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Chem 1508.82

The Gift of
the Author,
Charles Piazzi Smyth.

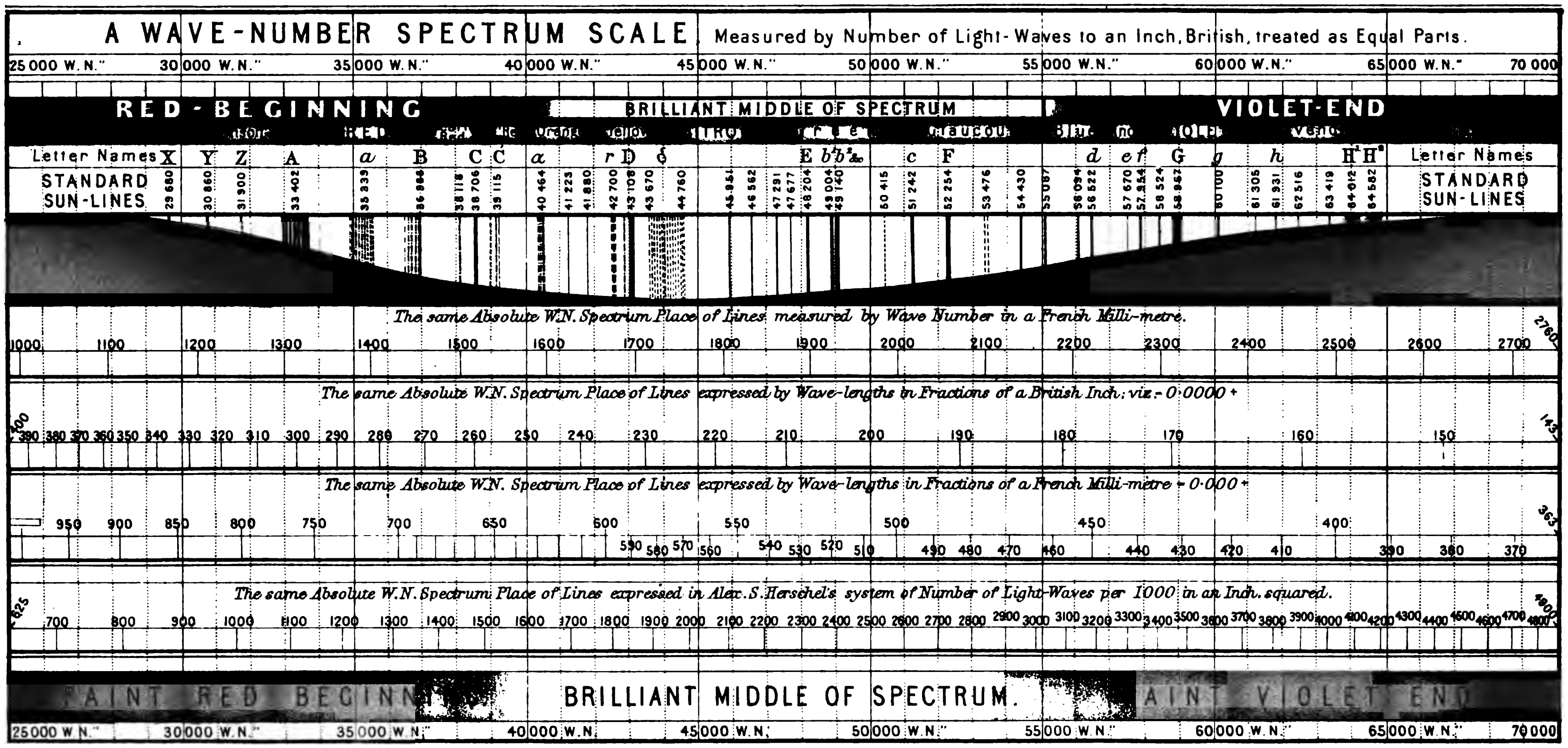
10 April, 1883.

OF

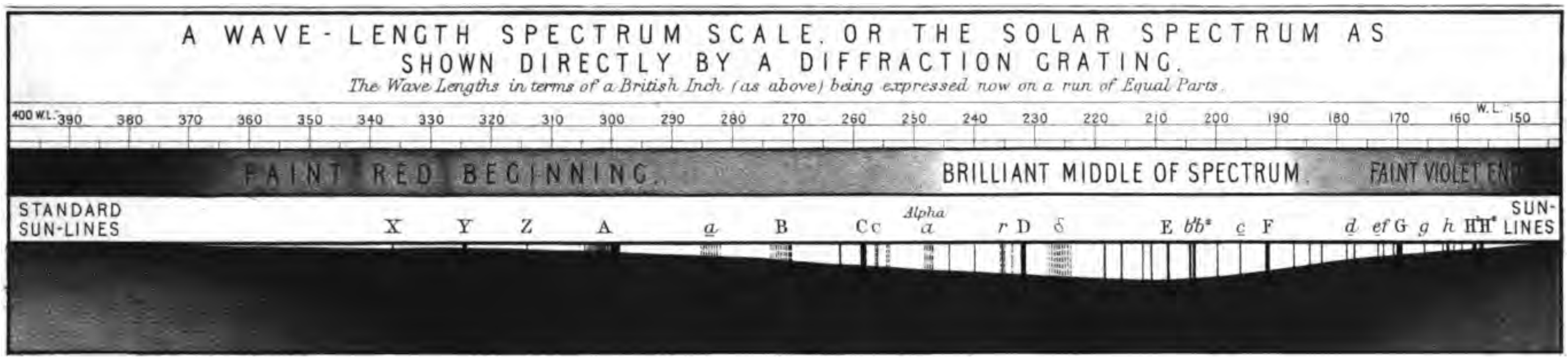
VARIOUS SPECTRUM SCALES.

APPLIED TO THREE FORMS, OR MODES, OF EXHIBITING THE SOLAR SPECTRUM.

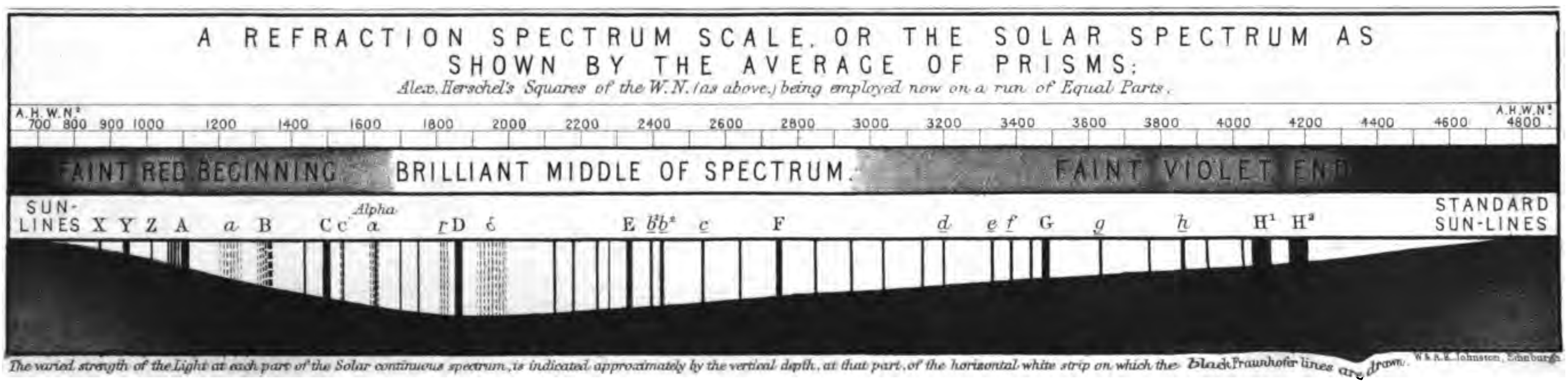
FORM I. WAVE-NUMBER SHAPE. *giving fair standing room, laterally, to both Red and Violet.*



FORM 2. WAVE LENGTH SHAPE; *Expanding the Red, and contracting the Violet, laterally.*



FORM 3. PRISM-SHAPE; *Contracting the Red, and expanding the Violet, laterally.*



The varied strength of the Light at each part of the Solar continuous spectrum, is indicated approximately by the vertical depth, at that part, of the horizontal white strip on which the Black Fraunhofer lines are drawn.

W. & A. K. Johnston, Edinburgh.

.Sival. h. 30.

Anal. p. 30.

MADEIRA SPECTROSCOPIC

BEING A REVISION OF 21 PLACES

IN THE

RED HALF OF THE SOLAR VISIBLE SPECTRUM

WITH A RUTHERFURD DIFFRACTION GRATING

AT MADEIRA

(Lat. = 32° 38′ N., Long. = 1^h 8^m W.)

DURING THE SUMMER OF 1881

BY

C. PIAZZI SMYTH

Astronomer-Royal for Scotland

BRAZEN-HEAD BEFORE FUNCHAL BAY, MADEIRA; at 4^h 50^m P.M. ♂ May 17, 1881.

Woodbury-typed from original drawing by C. P. S.

W. & A. K. JOHNSTON

Geographers, Engravers, and Printers to the Queen

EDINA WORKS, EASTER ROAD, EDINBURGH

1882

~~VI, 3032~~
Chem 1508.82

1883. April 10,
Gift of
The Author.

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MADEIRA, SPECTROSCOPIC.

PART 1.

INTRODUCTION AND GENERAL EXPLANATION.

RAPID as have been the advances of observation power in Solar spectroscopy during recent years, the progress of theorizing has been still more rapid. So far reaching indeed has been this growth of theory, calling, as it proceeds, for the most extensive changes in all terrestrial chemistry, that I have ventured to think, that some new, and if possible, improved instrumental examination should be entered on, to ascertain how closely the most improved map-versions hitherto in vogue, and on which the new theories largely rest, do really represent in certain crucial instances the exacter phenomena of the Sun's spectrum, as produced to the eye, through glass, by absorptions in the immediate Solar neighbourhood, apart from any effects of telluric or other origin.

But the atmospheric circumstances of the Royal Observatory, Edinburgh, are by no means favourable to such an enquiry. For year by year, with the growth of that city generally, and the manufacturing prosperity of its trading neighbour, Leith, the amount of coal smoke darkening the air, without any Municipal hindrance thereto, is continually increasing. The summers are generally cloudy; and the Sun, by reason of the high Northern Latitude of the situation, can never be seen anywhere near the Zenith, *i.e.* through the least thickness of the local atmosphere, such as it is. Nor is there any spectroscope, furnished by Government to the Observatory, capable of competing with, much less excelling (as it ought to do), any of the grander instruments which have been long since employed in Solar Spectrum work by the physicists of every independent nation.

But having been fortunate enough, in the autumn of 1880, to procure from America two fine examples of the Diffraction Gratings, ruled with such admirable truth by Lewis M. Rutherfurd, Esq., of New York, with 17,296 lines to the inch, over a surface 1·6 inch square on speculum metal, I proceeded to fit up one of them at home on the same table-stand that I had employed with prisms at Lisbon in 1878. The whole was a rough, economical affair to look at; but, thanks to the Rutherfurd Grating and its perfections, gifted with some powers of optical presentation far transcending anything that I, at least, had previously used,—so, my Wife accompanying, I took the whole to Madeira in the month of May 1881, a somewhat assisted passage in Sir Donald Currie & Co.'s splendid South African steam-ships * having been kindly negotiated for us by that long-continued friend of the poor Observatory, R. M. Smith, Esq., F.R.S.E., and Member of its Government appointed Board of Visitors.

Mathematical Geography had inevitably told us we should have the Sun in Madeira at the Summer Solstice, day after day, within only 10° of the Zenith; but Physical Geography stepped in between, and with a warm ocean current surrounding the island, produced (over and above transparent watery vapour to the n^{th}) such an endless supply of clouds, that there was hardly more than one day in ten when the Sun was visible in a pure blue sky. Yet that one day nearly made up in superior quality of Sunlight for the loss of nine days' quantity, in a kind of observation where, if one could not do better than almost every previous observer, there was little use in attempting anything.

We were stationed all the time of being on the island in the valley slope of Funchal, about 270 feet above the sea-level, at a garden villa formerly occupied by an American consul, now utilized as the very convenient "Jones' private hotel," highly appreciated by Madeira visitors and residents alike; and where the stone-floored smoking room, added in his day by the consular representative of the United States, served very conveniently as a heliostatic Observatory; for it gave a command of the Sun's path, from the time of its rising in the early morning over the distant promontory of Brazen Head, up to, and a little past, noon. We were well able, therefore, to follow the changes which different altitudes of Sun produced in particular groups of Spectral lines, and perhaps as favourably as in any other permanently inhabited and easily reached part of Madeira. For though, towards the end of our stay, some visitors suggested that we should have done better and enjoyed clearer skies in the open country far away from the basin of Funchal, we had had daily observation proof, through three months, that the clouds which did the main mischief in May, June, and July, were wide-spread, Trade-wind clouds extending over sea and land for many times the breadth of Madeira; and though the thickness of their whole stratum might probably have been transcended by climbing to the most elevated summit of the island, Pico Ruivo, 6000 feet high, that would have entailed an expense totally beyond my private means; while the money itself, had it been forthcoming in any other way, would have been better expended on the Peak of Teneriffe, where a greater height could have been obtained in a more Southern

* The R.M.S. "Dunrobin Castle," Capt. Harrison, going out; the R.M.S. "Warwick Castle," Capt. Robinson, returning; and Messrs Blandy Brothers, the courteous agents of the Company in Madeira, all kindly aiding and abetting.

Latitude, and at less expense; with the cordial and encouraging approval too this year, as I am enabled to add, by Don Antonio Aguilar, Astronomer Royal at Madrid, of both the Government of Spain and the Captain General of the Canaries.*

Returning then now for such work as was alone possible, to the Quinta do Corvalho, near Funchal, the instruments which we established there, were firstly a heliostat, capable of being protruded out of a black-curtained window, carrying a mirror 11 × 7 inches, silvered by myself on the upper surface, worked in angular position by long Hook's joint handles, and sending its reflected beam of Solar light first through a 6-inch achromatic lens of 90 inches focus, and then through a separating prism, of white flint, small refracting angle, but large size, upon the slit of the spectroscope. This slit was in focus of a collimating lens of quartz, 2·25 inches in diameter, and 31 inches focal length: through which the rays passed on to the Diffraction grating, and were viewed in reflection from that by a telescope armed with a quartz objective, also 2·25 inches in diameter, but with a focal length of 52 inches. This telescope was furnished with eye-pieces magnifying 30, 45, and 64 times,† and was employed on either the second or the third order of spectrum furnished by the grating.

The resulting spectroscopic observations almost necessarily took the shape of critical revisions of crucial groups of lines as already measured, pictured, and mapped by various standard authorities: besides comparing them directly with the living spectrum. To this end I not only took several sets of measures of each group as seen in the Sun, at both high and low altitudes on independent occasions, and prepared from the measures two drawings of each group from different days of observation, but also confronted every such drawing, when complete, with the Solar spectrum, to test still further its general likeness or deficiencies.

The published authorities (not all of them for the whole spectrum), thus tested, were—

(1.) Sir David Brewster and Dr Gladstone, in the "Philosophical Transactions" for 1860.—Their principal map is a carefully engraved copper plate in the ancient manner, but on too small a scale for comparison here, except for their specially magnified bits containing Great **A**, little **a**, Great **B**, the **Alpha** band and "little **b**," which do them much honour for their early day of activity and work. It is a prismatic or refraction spectrum.

(2.) Professor Angstrom's Normal Solar Spectrum, 1868.—This excellent map I have followed as the chief authority for the absolute spectrum places of all the principal lines, and for their chemical origination, so far as yet known. It is also most exemplary for the manner of its engraving—on stone, but not as a lithograph either of pen or pencil; for the lines were incised by a sharp cutting instrument, with an ultimate effect very like that of copper plate; and it comes nearer to what one sees, or the manner in which one sees, Solar spectrum lines in a good and narrow slitted spectroscopic instrument, than any other whole spectrum map I know of. As observed, it was a grating, or diffraction spectrum, and its chief power is therefore in the red half, though it only begins there with "little **a**."

(3.) Professor Kirchhoff and M. K. Hofman's spectrum, as presented to the British public by Professor Roscoe in 1869: and which, if not endued with all the authority of Professor Kirchhoff's original work, which I have not been able to obtain a copy of,—yet is thus recommended in the preface to Professor Roscoe's "Spectrum Analysis."—"For the permission to reproduce exact copies of Kirchhoff's, etc., map, I have to thank the above named gentleman." "Also, my thanks are due to Mr J. D. Cooper and Mr Collings for the very great care which they have bestowed upon the illustrations, and especially upon the difficult task of reproducing Kirchhoff's maps in four tints."

It was, indeed, a task so difficult, and in its method uncertain as well, that it is a pity they attempted it: especially as the four coloured tint stones for different intensities of black lines in the Solar spectrum not only do not represent what one sees there, but they are liable to variations of place in every copy between every successive printing, on account of errors of "registration" of the stones by the hands of the workmen. The spectrum is of the prismatic order, greatly compressed at the red, and elongated at the violet end, as is the manner of prisms; has no absolute scale, and its chemical origination references are not always so correct as those of Angstrom.

(4.) Any notable deficiencies in the above version of Kirchhoff and Hofman's map may perhaps be supplied by the more recent version by Dr Schellen, in his "Spectrum Analysis," as translated into English by the Misses Lassel; who, in their Preface (Date, Dec. 1871), speak of it thus:—"We are glad to have the opportunity of expressing our thanks; . . . to Mr Pearson for the careful manner in which he has conducted the engraving on wood of Kirchhoff's maps, so as to represent them in several tints, a task in which he has been materially assisted by the great accuracy of the printers, Messrs Watson and Hazell." It is, in fact, a case of printing from as many successive wood blocks as there are tints; and, therefore, like the tint printing in lithography, is dependent for exactness of place on the care of the workmen at every impression.

(5.) A lithograph prepared in Germany, for Lewis M. Rutherfurd, Esq., of New York, from his own unequalled photograph of the blue and violet half of the spectrum, taken with a train of white flint-glass prisms at a rather early period in the history of spectrum-analysis.—The date of the lithograph is, I believe, about 1874; and it differs wholly from the many tint-stones work of Kirchhoff and Roscoe, in so far as it is a chalk-drawing on one stone only, reproducing within itself as nearly as possible every appearance, whether of lines, bands, shadows, etc. seen in the photograph taken direct from Nature; and such photograph copies everything which is there, with far more minuteness, dis-

* See "Nature," p. 554, No. 598, vol. 23, for April 14, 1881.

† These quartz objectives, the eye-pieces and focussing arrangements, were made for me by Mr Adam Hilger, 192 Tottenham Court Road, London.

crimination, and faithfulness than possible to any ordinary scientist's hand.

(6.) M. J. Janssen's engraving of a high sun, and also a low sun, view of the solar spectrum from **C** to **D**.—This is a work of very accurate observation, with five prisms, and of most refined, almost microscopic, copper or steel plate engraving: its date may be 1874.

(7.) The Royal Society's (London) Second Himalaya Spectrum, through the agency of their voluntary observer, Mr J. N. Hennessey, of the Indian Trigonometrical Survey; and published in the "Philosophical Transactions" for 1875.—The instrument employed was a spectroscope with three compound prisms, expressly made for the service by Mr Howard Grubb of Dublin, at the order of the Secretary or Council of the Society. The great merit of the work is, that it endeavours to give both a high, and also a low, sun spectrum from the ultra-red region through all the spectral length up to the Great **F** line, in the centre nearly of the whole spectrum. The drawing is engraved on stone, in rather too mechanical a manner, but a very certain one: for there is only one stone and one printing, so that displacements of some lines with reference to others can never occur there.

(8.) A photographic copy of a large drawing, compiled from his own recent and most remarkable photographs of the ultra-Red region of the Solar Spectrum, was kindly presented to me by Capt. W. de W. Abney, R.E., in 1878.—This photograph, like that taken much earlier in the history of Photography, viz. in 1843, by the elder Dr Draper, shows chiefly lines which are entirely beyond the range of optical vision; but as it also includes the visible Great **A** and its preliminary band, it has served as a useful test to the Madeira eye-work on the same region. Capt. Abney's Spectrum so photographed was derived from a Rutherfurd Grating.

(9.) Professor S. P. Langley of the Allegheny Observatory, United States, published a pamphlet in 1878, giving measures and lithographic chalk-drawing views, of both Great **A** and Great **B** in the Solar spectrum, with their respective preliminary bands, as seen by him with a Rutherfurd Diffraction Grating.—It is a very advanced work, and specially memorable for his fine discovery of the duplicity of the lines of Great **A's** preliminary band.

(10.) M. Fievez, *Astronome Adjoint* of the R. Observatory of Brussels, published in 1880, through the Belgian Academy of Sciences, a short pamphlet and a plate containing additions, on a larger scale, to M. Angstrom's map of the little "**b**" group of lines.—The plate is an *engraving* on stone, and the spectrum method was a Rutherfurd Diffraction Grating.

(11.) Professor Vogel, of the "Astro Physicalischen" Observatory of Potsdam in Prussia, published in 1880 a grand Solar spectrum map, extending from near **E** to beyond **H** and **K**, as seen with prisms, and therefore well adapted to supply the deficiencies of Angstrom's grating-produced map, besides being on three times as long a scale.—Part of Professor's Vogel's work is based on eye-observation, and part on photographs; but both of them are published equally by the method of tint-stone lithography, whose general failings have already been characterised; and both of them, though derived from Nature by prisms, are presented in the very different proportions of a wave-length, or diffraction grating, scale of equal parts.

(12.) Lastly, Prof. Young of Princeton, New Jersey, U.S., was kind enough to send me, in March of the year 1881, a pencil sketch by himself of the Great **E** group of lines in the Solar spectrum.—It is on nine times the scale of Angstrom's Normal map, and is the most refined, exact, and altogether exemplary drawing of any part of the Solar spectrum I have yet had the fortune to meet with. It is a diffraction spectrum from one of Mr Rutherfurd's best and largest gratings, and the spectroscope was attached for the time to the 12-foot Equatorial of the Princeton Astronomical Observatory.*

To all the above spectrum representations, I have in my enlarged copies of them applied the more nearly uniform scale of Wave-numbers, in a British Inch; and on reducing my own micrometer observations to the same absolute scale and unit of measure, I had intended to express each result to five places of figures, or to represent the whole length of the spectrum from Red to ultra-Violet, by a scale of 40,000 equal parts or units. But the magnificent action of Mr Rutherfurd's grating, under the high magnifying power of the apparatus, and the fine quality of the Madeiran sun-light when seen at all, showed that the reduction must be carried to six places of figures, in order to do justice to the certainties of the view, and the probabilities † of the Micrometer measures.

A second reduction was therefore instituted, going to tenths of the above units; and though it could not improve the fundamental absolute places of the chief reference lines, taken from Prof. Angstrom, yet it perfected the differences of place amongst, and the thicknesses of, adjacent lines, as micrometrically measured, so very much, as to be ultimately found an essential foundation for preparing trustworthy drawings of what was seen in the spectroscope.

It is moreover chiefly, if not only, by drawings, that the results of this Madeira revision of crucial groups of lines in the Solar spectrum can be well, and at the same time easily and

* While actually at Press with these pages and plates (August, 1882), I have been favoured with a copy of a new and very remarkable Solar spectrum map, just prepared by M. Fievez, of the Royal Observatory, Brussels. The observations for it were obtained by the most powerful spectroscope yet heard of, viz., a combination of a large Rutherfurd Grating, having 17,296 lines to the inch, and two of the superlatively magnifo-dispersing "Christie" half-prisms, from the Royal Observatory, Greenwich. The map therefore can hardly fail to be one of the most advanced of the present day; and I have not scrupled, in deference to it, to knock out my Madeira duplicate or Example 7, in the several plates 12, 13, 14, 15, and 16; and propose to describe in the appropriate places of the letterpress what has been accomplished thereby. M. Fievez map, I should further state, is engraved on stone—on a single stone in M. Angstrom's very secure manner; seems to resolve every group or band into distinct lines; but represents true haze, as in the Hydrogen lines, by dotted surface shades, unexceptionably.

† The Micrometer readings were not so fiducial, on being compared day after day, as I could have wished: and I could not then detect why; but even with these residual circumstances weighing upon them, they required, as above, a longer spectrum scale to show their real deserts.

certainly, judged. In order therefore, to facilitate such a test, I have now exhibited in every one of the twenty-one cases or subjects inquired into, five examples of just so many of the various older authorities already alluded to, and so much depended on by the theorists: as well as two examples of separate Madeira determinations by myself.*

These twenty-one subjects then, and their 147 examples, have been compressed into 17 plates to be found at the end of the book: preceded, however, by a preliminary, frontispiece, plate explanatory of the particular spectrum scale or projection employed, as well as followed by a colour plate—*i.e.*, 19 plates in all; and each of them has been described pretty fully, as well as critically weighed, in a set of rather voluminous "Notes to the Plates," which form the next division of the whole paper.

After these "Notes," might have come, but for the expense, the most strict portion of the enquiry: viz., "the Numerical observations" themselves as reduced from the Micrometer readings into Wave-number places. These were all put through their first reductions by myself while in Madeira: but only partially through their second reductions. That work was therefore undertaken on my return, by Mr T. Heath, 1st Assistant Astronomer in the Royal Observatory, Edinburgh. And after that was done, he then performed for me the more responsible part of exhibiting, similarly with the plates, two distinct results of independent observations of the same groups of spectrum-lines, to indicate the probable error of any one observation; and finally, giving the mean of both, as the best single result possible from all the observations; but which, without the previous contrast of independent results, would have told nothing of how far the mere arithmetical numbers might be depended on for setting forth this kind of physical truth and fact.

The above tables are, however, duly preserved for future reference; as are also the daily hand drawings which I was accustomed to make of the condition of the Sun's surface as to spots during the whole period of the spectroscopic work.

Finally should come the daily Meteorological observations, to illustrate still more fully the immediate circumstances under which the Spectroscope observations were made; and to explain the excessive preponderance there of the lines of terrestrial watery vapour in the red, as well as perhaps the faintness, if not absolute extinction, of much of the violet, end of the spectrum. But as these Meteorological observations are rather bulky, and their reductions still more so, I beg to refer for them to my special book "Madeira Meteorologic."*

C. P. S.

* Except in the five plates, 12 to 16 inclusive, wherein I have replaced one of each of my two Madeira views, by the same part of the spectrum as given in M. Fievez' new and grand Solar spectrum map;—see the footnote to page 3, col. 2, par. 2.

* Published by Mr David Douglas, 9 South Castle Street, Edinburgh.

MADEIRA, SPECTROSCOPIC.

PART 2.

NOTES, EXPLANATORY AND CRITICAL OF EACH OF THE PLATES

Plate 0, or Preliminary and Frontispiece Plate showing various Spectrum Scales, applied to three forms or modes of exhibiting the Solar Spectrum.

(1.) The uppermost of the three compartments of this plate contains a miniature view of the whole Solar Spectrum; not, however, in the relative proportions in which it is ever seen,—either with prisms refracting, on one side, or with gratings diffracting on the other,—but between the two; or as it is bound to appear virtually when laid off according to the number of Waves of Light in each part of the spectrum; and expressed in terms of any given unit of length measure, taken as a scale of equal parts.

For a British publication like the present, and also as offering a very convenient set of numbers in practice, the unit employed in the uppermost and lowermost lines of this top compartment of Plate 0, and afterwards through all the large spectrum drawings of this book is, that very nearly earth's axis evenly commensurable unit, the British Inch. This being accomplished by giving the number of Waves of Light, in the length of 1 British inch, whence there results 30,000 for the Red, and 60,000 for the Violet, end of the Spectrum.

In the third horizontal line or strip of this topmost table, the chief colours manifested in each part of the spectrum are approximately placed and named (though for a fuller account of that subject, see Plate 18 and its description at the end of these Notes).

In the sixth horizontal strip are represented the stronger of the well-known dark "Fraunhofer" lines, successively crossing the bright *continuous* spectrum of the Sun; the varying brightness of the different parts of that continuous spectrum being approximately indicated by variations of the vertical depth of the white horizontal strip on which the said lines are drawn vertically and parallel.

Underneath that space, with its complementary black shading increasing towards each end, are represented four numerical scales, more or less frequently employed among other spectroscopists; and a vertical reference carried down through them will give the reading of any particular Fraunhofer line, or of any of the here adopted Wave-numbers, on each of those other systems. Of course only roughly: but easily, and perhaps usefully, as a hasty, ready index for reference to many spectroscopic works.

(2.) The middle compartment of the whole plate shows, on the very different Wave-*Length* Scale, the excessive expansion of the Red, and the equally extreme contraction of the Violet, end of the Spectrum; whenever, no matter how it was observed, any "Wave-Length" scale is made use of, in equal parts, for plotting the observations. It is necessarily an excellent scale for the particular purpose of Wave-lengths alone, as well as correctly representative of spectra when shown by Diffraction Gratings; but it does not give sufficient space for the immense numbers of lines which do exist, and prisms show, in the violet region of many spectra, and of the solar spectrum in particular.

(3.) The lowest compartment shows the opposite exaggerations of prism-formed spectra. Not, indeed, with exactitude; for no two prisms act precisely alike on different parts of the spectrum, but sufficiently near to the generality of them to be practically employed for any one prism in particular: and then with the great additional advantage of its being an absolute scale in Nature—for which quality it was recommended many years ago by Professor Alexander S. Herschel, of the College of Science, at Newcastle-on-Tyne.

In each of these three different forms of exhibiting the spectrum, I have designed rudely, and from my general impressions only, a curved figure to show something of the comparative intensity of the light in different parts of the continuous spectrum of the Sun. No measures of that kind were attempted by me, for they are not necessary to the object of the present work, which deals only with the place and look of each Fraunhofer line. But it is approximately serviceable to know whether, as the light of the spectrum has a gradual beginning out of nothing visible, a brilliant middle, and then a slowly fading away into darkness at the end,—to know, I say, whether in measuring any difficult object, the observer had roughly enough, or too much, or far too little light; for, especially in the latter case, his measures cannot be equally exact with those in the first case. No normal statement however, for all, can be given; for while prisms condense the spectrum towards the Red, and gratings towards the Violet, that condensation alone does not determine the whole question of brightness; for some prisms absorb certain of the rays in greater or less degree by the colour of their glass; and some gratings by the untowardness of their speculum metal to reflect blue and violet light, do mar the visible presentation with such intensity as to overpower the optical condensation in gratings of that end of the spectrum. Anything, however, I presume, is better than to represent the whole continuous spectrum between two horizontal, parallel lines, as if it were of the same brilliant intensity the whole way along, and had neither beginning nor end of light short of infinity.

PLATE I.—SUBJECT 1.

GREAT A: ITS PRELIMINARY BAND ALONE, IN A HIGH, AND ALSO A MEDIUM HIGH, SUN. SEVEN EXAMPLES OF ITS TREATMENT BY VARIOUS AUTHORITIES. THE SPECTRUM COLOUR OF THE REGION IS A DEEP RED, BUT ITS LIGHT INSUFFICIENT.

EXAMPLE I.—From Sir David Brewster and Dr Gladstone, in the "Philosophical Transactions" for 1860.—When setting out on this whole enquiry, and proposing to compare my own observations very critically with the best of recently published spectra, I had not at first thought of going back further than the date of Professor Kirchhoff's magnificent work, which raised up a new standard of excellence before all the observers of the world. But Sir David Brewster's well-known exceeding efforts, in his earlier day, to study the Red Regions of the spectrum did really impart so much of superior quality to his views of both Great "**A**," little "**a**," and Great "**B**," that I was soon led to see, that it would be only paying a proper tribute of respect to his transcendent name in optical investigations, to introduce here some of his pictured representations of these parts. They form, moreover, in themselves such typical cautions of how Solar spectral lines have been in the past, and should be in the future, represented in published Memoirs, that I may as well set forth at once, on their foundation, the special principles which I have found it both expedient and economical to follow in the present book, when estimating old authorities, and striving to reproduce their works with the fewest uncertainties; as well as for picturing the chief results of my own observations.

A perfect reproduction by engraving of the exquisite refinement and varieties one sees of lines and shades in the Solar spectrum, not to say anything of colour, would be difficult to impossibility, and exceedingly expensive. Much may therefore be done by assisting any drawing or engraving with a few conventional symbolical rules, so as to represent thereby, more easily to the hand and more distinguishably to the eye, refinements and microscopic characteristics of delicate shades, and sometimes thick and black, sometimes thick and pale, and sometimes almost vanishingly thin lines in the Solar spectrum (all of them the "fixed lines" of Fraunhofer, but the "Fraunhofer lines" of the world). Every modern spectrum being represented with its length horizontal, the important dark and so-called Fraunhofer lines therein are all necessarily vertical. When they are thick, black lines, they can, or should, be mistaken for nothing else; but when they are sometimes thin, pale, and close together, they may very often be confounded with certain other vertically ruled lines, wherewith engravers so generally like to express shaded surface. Or, again, the latter kind of mechanical lines may be mistaken for the former optical ones, so as to be often misinterpreted, for an intention by the observer concerned, to assert that he had actually resolved what was, to other spectroscopists, a single, into a double or treble, line; or a mere cloudy, shaded space, into many distinct, sharp, independent Fraunhofer lines: a falsity of the most reprehensible and mischievous kind.

Hence my practical rules are—

(1.) Any vertical line, if introduced into the drawing or engraving of any spectrum, is to be understood as representing a clearly seen vertical line in the spectrum, and nothing else.

(2.) Greater or less thicknesses of black lines in the spectrum are to be represented faithfully by greater or less thickness of engraved lines on the map. And more or less of accompanying paleness of any such line may be indicated either by dotting, stippling, or cross-line etching the space it covers; or, far more easily, by shortening its height in the spectrum-strip, or by both methods together.

(3.) Very thin hazy lines in the spectrum may still further be represented by vertically dotted, or vertical linearly wavy, lines, or such *shorter* figurings in ink, as would, if smeared vertically through the whole height of the spectrum-strip, produce a line of less depth of tint than the full blackness of the printing ink employed.

(4.) Broad and very pale lines, and faint, hazy shaded portions of the spectrum will also be evidently representable by similar breadths on the map, but shaded by more or less closely ruled thin lines, drawn *in any direction except the vertical;* and the intensity of such shaded breadths may be assisted either by crossing or recrossing the shaded lines, or by giving the spaces covered by them greater or less vertical height. If such a shaded surface, or "band," in the spectrum be sharp, intense or dark, on one side, and shaded off on the other, its reproduction in the map should be a shading vertical on one side, and slanting on the other. While, if a cross-shaded vertically placed breadth, intended for a broad but pale line, or narrow band, does not look artistically firm enough without some kind of outline on either side of it, such lines may be put in if made minutely wavy, but never as straight and smooth, *vertical* lines: for then they might be mistaken for that most precious physical thing, a true and sharp spectral line.

Now, in the present Example 1, from Sir David Brewster and Dr Gladstone, *per* the Royal Society, we are met at once with their engraved fact that every line in the preliminary band of Great **A** is represented by two close, parallel, vertical engraved lines! Wherefore comes the question, What did they mean by that figure? If they really meant that they saw every one of those spectrum lines *double*, they would have eclipsed all subsequent observers up to and including Prof. Langley, of the Allegheny Observatory, in 1878, though he was, I fully believe, the first of mortal men really to see and publish the fact of that most transcendental duplicity of those grand lines at the practical beginning of the spectrum. But the two earlier observers have totally omitted so many other features far easier to recognise, that I can only, in honesty as well as loyalty to science at large, conclude that they saw the now confessed Double lines of Professor Langley as single ones; but saw them so pale, that they represented them on the copper plate by two thin lines close together, rather than by one thick, blacker and more decided, one. And this is a sort of case entailing possible injustice against posterity, and mischief at present, which we shall be required to judge of very frequently throughout this enquiry; especially in whatever of it emanates from the Royal Society.

But, simultaneously, with the above difficulty, there evidently came up the discussion of a further rule to be followed in this book, viz., On what scale, for size, should an older observed, and generally much smaller, spectrum-map, required for comparison with my observations, be represented?—of its own original small scale?—or on the larger size adopted by me in my MS. drawings, and wherein I followed the excellent specimen by Prof. Young of Princeton, U.S., already alluded to on page 3?

If, on the original small scale, it would not look like justice to a predecessor, and would leave the public with all the difficulty still of comparing, very small with great; and puzzling out every time *de novo* with a magnifying glass or a compound microscope, the meaning of vanishing traces of difficult lines and wrongly indicated shadows. But if, on the large modern scale, the old drawings would look rough, rude, and coarse; though extremely easy to compare and understand, by adopting with them the symbolic methods just arranged for physical truth's sake, rather than pictorial effect. On the whole, therefore, I have thought it better to magnify all the old drawings up to the size adopted for my own work; to symbolise their shadings; and to palliate, or apologise for, the sometimes coarse, Cyclopean look thus imparted, by giving both the dates at which they first appeared, and the number of times linear they have been magnified by me, in breadth.

With this explanatory statement, therefore, once for all, I now leave my magnified representation of Sir David Brewster and Dr Gladstone's view of Great **A**, as Example 1, of Subject 1, Plate 1, to speak for itself; and it will probably be admitted by all persons to be a very advanced work for its date of execution, showing, as it does so clearly, more knowledge of the rythmical construction of that grand beginning of the now generally known Solar spectrum in the Deep-red, than has been enjoyed by many subsequent observers. But yet not enough to content all the demands of science in the present day.*

Example 2 of Subject 1, Plate I.

This is taken from Professor Kirchhoff's and M. K. Hofman's map, as reproduced in this country by Professor Roscoe. The spectroscope with which the two former gentlemen worked must have been of great purity of vision, combined with much power and unusual capacity, for showing thin, faint lines. But it does not seem to have been sufficient to split each of their several lines in the preliminary band of Great **A**; and that said band is sadly disfigured and perverted out of its rythmical symmetry by the abrupt steps of gradation from one tint-stone to another. Its date is supposed to be 1869.

Example 3 of Subject 1, Plate I.

This is the view contained in the "Philosophical Transactions" of the Royal Society for 1875. Being the second such spectrum which that learned Society has published, and on the strength of observations made by their observer in India, with a *second* spectroscope which the Society had made and sent out to him,—unparalleled refinements were expected from it. The preliminary band of Great **A** is indeed represented there as surcharged with innumerable thin vertical lines, and some broken speckling here and there; but due consideration of all of them leads to the firm belief that they are merely engraver's lines to represent uniform shade, excepting so far as the speckling may indicate some suspicion of possible resolvability into lines of a wider kind. So that the true nature and construction of **A's** preliminary band has been missed by the Society, to a degree that can only be relegated to the days long before both Professor Kirchhoff and Sir David Brewster, though really so much later.

Example 4 of Subject 1, Plate I.

This is from a photographic copy of a hand water-colour and inked drawing, prepared by Capt. W. de W. Abney, R.E., from his celebrated photographs with his own prepared *red* molecules of silver, of the Infra-Red end of the Solar Spectrum, in or about 1878, with a Rutherfurd Diffraction Grating. It evidently restores the resolution of the Royal Society's nearly impalpable haze-band into thick vigorous lines, with a considerable amount of rythmical force: and also adds the extreme line on the right of the band, though not knowing why it was so much thinner than those which follow it on the left. This notable discovery was reserved for

Example 5 of Subject 1, Plate I.

This is derived from Professor Langley's observations in the Allegheny Observatory, U.S.A., taken by eye-observation with a Rutherfurd Grating, and published by the "American Academy" in 1878. The plate given there is a lithographic chalk-drawing on a very fine-grained stone, with the lines all of equal height, but of delicately varied strength of tint, such as only fine chalk work can realise. As I do not expect to be able to multiply my drawings in that way, I have brought in, by the symbolical rules already alluded to, a difference of height in the lines, to indicate that the same paler effect is intended here, though my lines, as high as they go, be absolutely black.

But the one surpassing merit of Professor Langley's work, viz.,

* The size adopted in my MS. drawings for all spectra referred to, and for my own also, is about nine times as large as Angstrom's in the Green part of the spectrum, and would be about 120 feet long for a continuous map from **A** to **H**; but being a map of Wave Number, it varies its proportions on Angstrom's, which is according to Wave lengths, in different parts of the spectrum; the multiplier required to bring up Angstrom's being smaller at the Red, and greater at the Violet, end. But the size of my MS.S. drawings has been reduced, since the above was written, 1·33 times in the process of photo-lithographing, to suit the size of these printed pages.

the duplicity of every line in the band, except the one on the right-hand side, is equally clear in either his or my method of representation.

EXAMPLE 6 OF SUBJECT 1, PLATE I.

This is mainly from my own observations at Madeira on July 9, at 8h. A.M. For after that, it was confronted with the spectrum on July 18, near noon,—and then slightly corrected as to its general physiognomy.

I had looked at Great **A's** preliminary band several times previously, as in May and June, and equally also with the Rutherfurd Grating, but without seeing it sensibly different from what I had represented it by means of my Lisbon prismatic observations of 1877, pictured in the xivth vol. of the "Edinburgh Astronomical Observations," and described in the "Transactions of the Royal Society, Edinburgh," for 1879. But I presently realised, at Madeira, that I had opened the slit of the spectroscope too wide, with the object of correcting the lamentable fading away of the general light in **A's** part of the continuous spectrum; for as soon as I had narrowed the slit to the same extent as found most conducive to good definition alone, in the brighter regions of Great **B**, and then turned it on the preliminary band of Great **A**, and readjusted the focus,—instantly the duplicity of the whole of the lines started, leapt, into view with a distinctness, combined with number of cases, and rythm of variation in intensity and distance, which made it the crowning group of the whole spectrum for beauty and effect. The definition, too, was such, that the clear burning Crimson, or Deep Red colour of the continuous spectrum appeared as brightly between the components of every pair of lines, as in the greater distances between pair and pair; and I was able with perfect ease to measure not only the distance from pair to pair, and from component to component of the seven or eight concluding pairs, but the thickness of every line therein; placing the needle-pointer first on one edge of a black line, entering the reading of the micrometer in the ledger, and then similarly treating the second edge of the same line,—a Fraunhofer line in principle, but of a grandly harmonic order beyond any that he was privileged to see.

The chemical origin of these lines, if telluric, is certainly not watery vapour, nor anything confined like that, chiefly to the lower strata of the atmosphere; for their appearance changes so very little with greater or less altitude of the Sun. Some dry gas in the upper regions of the earth's atmosphere, or perhaps in the outermost and coolest envelopes of the Sun, or in the 92 millions of miles of space between, must be sought for: and *not* by the method alone of trying to make its lines appear bright by induction-coil electric discharge through it, as in ordinary heating gas-vacuum tube experiments, but by the cold absorption method of looking through 500 feet long metal tubes, with glazed ends, and filled in succession with every known gas, at a light of constant quality. The wealth of great London and its richly endowed Scientific Societies may be sufficient for this important step towards removing an ignorance which now blocks the way at the very beginning of Solar eye-sight spectroscopy; but no starved establishment in the Provinces, no Astronomer-Royal for Scotland, with half the salary of a clerk in some London Government Offices, need be expected to attempt it.

EXAMPLE 7 OF SUBJECT 1, PLATE 1.

This is little more than a repetition of Example 6 (on an independent footing, and without looking at the former records), to serve now by its agreements or disagreements to indicate within what amount of spectrum place we have at last attained to the true appearance and structure of the preliminary band of Great **A**.

PLATE II.—SUBJECT 2.

THE GREAT **A** LINE ITSELF (SPECTRUM COLOUR A DEEP-RED, BUT LIGHT VERY FAINT) IN A GENERALLY HIGH SUN: REALLY A GROUP, OF MANY MOST STRIKING AND CLOSELY ARRANGED LINES.

EXAMPLE 1.—From Sir David Brewster and Dr Gladstone in 1860.

There are here merely three blocks or bands of shade (shaded, too, in eminent honesty with *horizontal* lines, so that they can mean nothing but shade), a sufficient proof that the duplicity of the lines of the preliminary band could not have been seen by these celebrated observers, and was not intended to be shown by their double engraved vertical lines, already alluded to under Example 1., Plate I.

EXAMPLE 2.—From Professor Kirchhoff and K. Hofman, *per* Professor Roscoe.—There is here an advance: more breaking up of the whole mass of Great **A** into several sub-divisions; but these have not yet touched the really crucial point for definition and progress, as will be seen further on.

EXAMPLE 3.—From the Royal Society's second Himalaya Spectrum in their "Philosophical Transactions" for 1875.—The only movement here is backwards into absolute night and darkness.

EXAMPLE 4.—From Captain W. de W. Abney's photograph in 1878.—Great **A** is here restored to the state nearly of Kirchhoff and Hofman's view, but must evidently have been taken with too broad a slit for fine definition.

EXAMPLE 5.—Professor Langley's view from the Allegheny Observatory in 1878.—Here we may immediately see that Professor Langley has resolved the duplicity of the earlier lines composing Great **A**; but he is troubled with an amount of shade over the whole, which I hardly understand; and he says of it, "The position of some of the lines in this wide band is uncertain, on account of the darkness of the field. It is not clear how far the greater apparent width of the lines in the pairs than in those of 'Great **B**' is real, and how far due to the need of a very wide slit."

EXAMPLE 6.—From my own observations in Madeira, in both a rather low and a very high Sun; the two appearances, very little different from each other, being combined in one and the same view.—The chief point to notice is, that not only was Professor Langley's duplicity of the first three lines confirmed, but the first two of them were found as signally clear and free from all haze, and with bright red light shining through between the components of one of the doubles, as between double and double, or even between the whole line group, "Great **A**," and its preliminary band in Plate 1. There was also an approach (often a confusion, indistinctness, and darkness in the middle of the group) to the same breaking through of light (as it almost seemed from behind) in the ante-penultimate part of the whole structure; and this, when the slit of the spectroscope was so very narrow as to show the two exceedingly thin lines which follow, well. If this transparency, or continuous illumination of the back-ground of both the beginning and ending, of the whole general region of "Great **A**," is not so well shown in Professor Langley's view: it is probably an indication that his sun-light was not so concentrated or bright as mine, while the definition of his apparatus was unapproachably fine.

EXAMPLE 7.—This is my second set of observations of "**A**" in Madeira, both taken under a high Sun on July 9, and tested under similar conditions on July 18, 1881.—The second evidently confirms the first set in every main particular or feature wherein that set differed at all notably from any of the previous observers. Wherefore, here again, with the Great **A** line itself, we have undoubtedly the most stupendous existence, so to speak, in all the visible part of the Solar spectrum; and yet, so unequal, or partial have been the Metropolitan researches, with their immense concentrations of Government aid, into Solar spectrum analysis, that nothing whatever is yet known of what makes "Great **A**;" though in other parts of the spectrum many a single line, not thicker than a thin spider's thread at a distance of 20 inches from the eye, has long since been assigned to the particular metal which alone can, and does, cause its appearance there.

PLATE III.—Subject 3.

Little **a**: its own group of lines; in the Spectrum's colour-region of pure Red; light stronger than at **A**, but still rather too weak for best observing.

EXAMPLES 1 and 2.—These are both of them Professor Angstrom's views of the group *little* **a**, ascertained by him to be caused by the invisible watery vapour always contained more or less in the lower parts of the earth's atmosphere.—He shows in all 14 lines in each view; in the upper, or in a high, Sun view, 9 of these lines are hazy; in the lower, or low Sun, view, 12 of them; and all these last, both to a much darker degree and with a filling up also of all their intervening spaces, with obscuring haze.

In the high Sun view some of his thicker lines have thin and finely engraved lines on either side of them, looking under a microscope like systems of triple spectral lines proper; but the lateral adjuncts I can only look on as the engraver's method of representing a narrow haziness of border, or outline, of each principal line. In the lower Sun view the denser and broader haze which comes in there is represented unmistakably by crossed line-shading, which can mean nothing but general haze or darkness.

EXAMPLE 3.—Professor Kirchhoff's and M. Hofman's view, *per* Professor Roscoe.—There are here 16 or 17 lines, of which 8 are terribly black by being printed from the black-ink stone; while the others are various, printed from two, possibly three, differently coloured tint-stones, one of them of almost vanishing paleness. Notwithstanding all the coarsenesses of this lithographic method, and perhaps of my magnifyings thereof in addition, there may yet be traced a considerable resemblance, most unexceptionably arrived at, between this view by Kirchhoff and Hofman, and Professor Angstrom's more delicately engraved drawings.

EXAMPLE 4.—This is a view by the Royal Society, London, representing "little **a**" in a high Sun in the Himalayas, and contains only 7 lines.—The two thicker of them are indeed formed in the original engraving, the one by three, the other by four, as distinct and separate vertical lines as any engraver could draw; and each of such component lines is of exactly the same make, as either one or other of the widely apart single lines proper, either preceding or following the two multiple sets. Yet, withal, I have no doubt that the three and the four thin lines making up these two broad bars or bands, are nothing but engraver's "shading lines," which, instead of being made up of short lengths placed one over the other horizontally or diagonally, are set up vertically, or precisely in the position that should have been most studiously avoided, to prevent readers and lookers on being utterly misled.

EXAMPLE 5.—This is a magnified representation of my own view of the "little **a**" band, as given, in numbers and words only, in the course of my Lisbon observations of the whole Solar Spectrum, taken in 1877 and 1878, with prisms in a high Sun, and printed by the Royal Society, Edinburgh, in the xxixth vol. of their "Transactions."—It is essentially an observation in a dry climate, as will come out in contrast with—

EXAMPLES 6 and 7, or my two Madeira views of "little **a**," not at all in a low, but in a medium-high, and a very high, almost Zenithal Sun. One of them contains 42, the other 44, lines. The latter's two extra lines are easily accounted for by better definition on the second occasion; and then, either view supports the other in its extreme antagonism to all the first five examples by other observers, and by myself also when in Lisbon.

There are two reasons for this:—*1st*, the splendid action of Mr Rutherfurd's Diffraction Grating, in Madeira, enabled me to use such high magnifying powers with advantage and exquisite definition, as necessarily left previous observers generally far behind. *2nd*, the one chief and abiding feature of the climate of Madeira, reacting on its vegetation, its products, and its people—as I hope to have proved in the recently published book, "Madeira Meteorologic"* — is the immense amount of invisible watery-vapour always present in its atmosphere; and hence the tremendous as well as beautiful crowds of lines in the group of *little* **a**, when seen there, even in a high summer Sun. In Portugal, both in 1877 and 1878, where wet and dry thermometers showed three, four, and even five times as much difference the one from the other, as in Madeira with a nearly similar temperature, a noon-day view of *little* **a**, gave forth, as shown in Example 5, little, but the thinnest possible lines over any part of its area; and if the same apparatus had been erected in those other still drier regions during summer time, viz., the lava-rocks on the Peak of Teneriffe, at a height of 10,000 feet above the sea-level, it is quite possible that *little* **a** and all its satellites would have ceased to have any apparent existence in the Solar spectrum. In which case how would not their absence have aided the investigations of any Solar physicist into his rightful arena, viz., the Fraunhofer lines produced by the Sun's absorptive atmosphere alone; while the Terrestrial physicist would also have profited from such a series, continued from Sun-rise to Noon, and from Noon to Sunset, by learning exactly what lines were the sole production of the *dry* gases necessarily constituting the bulk of the *Earth's* atmosphere, but more particularly of its upper regions not yet experimented on by chemical analysis.

PLATE IV.—Subject 4.

Great **B**: its preliminary Band in a High Sun. The Spectrum Colour of the Region, a pure and perfect RED. The Light of the Continuous Spectrum now sensibly stronger, and fit for nicest observations.

EXAMPLE 1.—This picture is a magnified copying from Angstrom's Normal Solar Spectrum, and is greatly to his credit as an observer, who made the best possible use of the apparatus in his hands; but which, though remarkable in his day, has been since then (and not immediately after him) far transcended.—A point specially to be noted in his favour is the difference which he makes in the line 36,743, as compared with the lines preceding and following. The smallness of his spectroscope prevented his seeing the absolute nature of any of these lines; but yet he saw a difference, and expressed it so characteristically, that we can have no doubt, on looking to Examples 5, 6, and 7, that his eye was true and far in advance of what it had to look through.

EXAMPLES 2 and 3, or the two British editions of Kirchhoff and Hofman's map, are partly murdered by the coarseness of the tint-stones or tint-wood blocks they are printed from, and partly by the over-broad slits and too small dispersion of the prisms they were observed with, so that they show no advance over Angstrom with time, but rather the contrary.

EXAMPLE 4, by the Royal Society, London, in 1875, exhibits this retrograde march of observation still more decidedly, though in a different line; but

EXAMPLE 5, by Professor Langley of the Allegheny Observatory, U.S.A., with a Rutherfurd Diffraction Grating, has taken up the onward course of science again, and is fully worthy of the present day. Nor is it a view which can only be obtained by a grating, for I observed it very nearly, if not quite as well, with prisms at Lisbon in 1878, and was so much struck with its beauty and rythmical gradation of steps that I sent a special notice of it that same autumn to the Royal Astronomical Society, without then being aware of what Professor Langley had done in that self-same summer. But I prefer now to rest on my Madeira observations, in **Examples 6 and 7,** for my best views of the preliminary band of Great **B** in a High Sun; and the importance of that subject in the spectrum is so great, on account of the mathematical, and evidently some-day computable, character of its doublets of lines, that I hope Professor Langley will revise his observation of the 8th couplet from the right, and see if the intrusive line which makes it a triplet is not, as I have represented, outside, not inside, the normal pair.

It was the fact, however, as I believe, of such an intrusive line, paler than the others, and widening out the space set apart by Nature for the doublet proper, which caused Angstrom to represent that group as broader and paler than the bars both preceding and following: for these he represented as hazy single lines. We know now that they are clear doubles, and his making them single, but hazy, was quite an ordinary effect to be expected from his imperfect apparatus. But what is the meaning of the dark dotted matter filling up the interstices of the three or four last and most conspicuous of his pairs? when in both Professor Langley's and my own, views there is not a particle of such shade or matter between either those or any other of the doubles.

Many experiments which I have made show such a filling up to be a manner of failing peculiar to spectroscopic vision, when pushed rather too far. Spectroscopic observation is mainly the viewing of thin, parallel lines, side by side; and as the late Professor Phillips of Oxford well showed, far more minute thicknesses could be distinguished by the eye, when they formed the transverse breadth of long bands, than the diameters of small circles: whence the well-known efforts of all star spectroscopists to make linear figures of their round stars, by the introduction of cylindrical lenses, whence they obtain broad spectral strips and lines across, not dots therein, to mark them. That advantage however gained, there remains this curious defect, that whenever the definition of two close spectrum lines begins to fail,—whether from disturbance of the atmosphere, failure of light, defect of instru-

* Published by David Douglas, 9 South Castle Street, Edinburgh, 1882.

ment, or fatigue of the eye,—such two very close lines begin to throw out a haze towards each other, completely thatching in, as it were, the intervening space, while their outer-sides remain sharp and well defined: at least until the haze becomes still thicker, and then both sides of any line group become indistinct. Hence we may be quite assured that the apparently solid and physical material, or filling up of the interior spaces of Angstrom's three last doubles, has no real and *bonâ fide* existence in Nature; but is a proof of the bad definition of his grating, and forms an optical effect or defect which a spectroscopist must be always on his guard against being misled by.

PLATE V.—Subject 5.

GREAT **B**: ITS PRELIMINARY BAND AGAIN, BUT NOW IN A LOW SUN. SPECTRUM COLOUR OF THE REGION, A PURE AND PERFECT RED.

EXAMPLE 1, from Angstrom, shows every line greatly thicker and blacker than before, with immense increase of general and wide-spreading haze.

EXAMPLE 2, is Sir David Brewster's drawing, supposed to have been executed at a still earlier day, and giving some lines, but chiefly haze.

EXAMPLES 3 and 4, are the two British versions of Kirchhoff and Hofman's map, with some haze added by me to justify their general descriptions as applied to their drawings; and enable them, from their pictures in a high, to represent a low, Sun view.

EXAMPLE 5, is the sadly backward account of this remarkable system of lines given by the Royal Society, at their second attempt in 1875.

EXAMPLES 6 and 7, are my Madeira observations, reasserting in a low, the rythmical duplicity of the lines seen in a high, Sun: introducing many new lines, clearly convicting the outside line of the triplet at 36,744, of being an abnormal intruder, and declaring most magnificently that all the particular haze between the components of Angstrom's doubles, and all the general haze over the whole constellation, as it were, of this group of lines, is nothing but want of good optical definition in the spectroscopic apparatus employed by him; for sharper, clearer, blacker lines on the brilliant scarlet-red of the Sun's continuous spectrum in this region, I have never seen and could not well imagine.

PLATE VI.—Subject 6.

THE ATTACHED BAND OF GREAT **B**, IN A HIGH SUN. THE COLOUR OF THE CONTINUOUS SPECTRUM OF THE REGION A PURE AND PERFECT RED.

This is a much more difficult subject of observation than the preliminary band on account of both the thinness and closeness of the lines.

EXAMPLE 1.—Shows that even Angstrom could make little of it beyond two pairs of widely separated coarse doubles, and a very thick club of a line with haze, at the end of the group.

EXAMPLES 2 and 3, would claim by sundry very thin lines scratched on tint-stones or tint-wood blocks that they had seen the greater part of the band resolved into its component elements of true spectral lines; but the lines they show are not the right lines, and they omit other lines near the end of the group far easier to see; wherefore I conclude that their thin tint lines, are little more than engraver's shadings, and I have symbolized them accordingly as such in my enlarged copies; but still, with a doubt interpreted in favour of Professor Kirchhoff and M. Hofman having seen some approach to the band resolving into lines, and having therefore instructed their engraver accordingly

EXAMPLE 4, shows the Royal Society, London, at a much later date repudiating all idea of many fine lines, and acknowledging only three degrees of broad shade.

EXAMPLE 5, exhibits the whole group, under the scrutinizing gaze of Professor Langley, of the Allegheny Observatory, U.S.A.; when it breaks up easily into 17 lines, every one clear, sharp and distinct except the last two.

EXAMPLE 6 and 7, from my Madeira observation, fully confirm Professor Langley's improvements; even clear his last pair of lines of all haze, and indicate a possible splitting up of his very thick line at 36,982, into a double.

PLATE VI.—Subject 7.

THE ATTACHED BAND OF GREAT **B**, IN A LOW SUN. THE SPECTRUM COLOUR A PURE AND PERFECT RED.

EXAMPLE 1, shows Professor Angstrom representing this difficult group very like his high Sun view of it, but with the lines thicker and more overlaid with haze.

EXAMPLE 2, is an excellent proof, for its day, of what Sir David Brewster saw and published in 1860 with Dr Gladstone; and is noteworthy for the very complete separation of the so-called "attached band of Great **B**," from the thick **B** line itself.

EXAMPLES 3 and 4 are merely repetitions, with a little more depth of shade, of the examples 2 and 3 of Subject 6, viz. the two British reproductions of the one original Map by Kirchhoff and Hofman.—They *should* be precisely alike, but they differ from each other in a most curious manner, one coinciding with Angstrom as attaching the band to the strong line, and the other agreeing with Brewster in completely disconnecting it.

EXAMPLE 5, is by the Royal Society (London) representing nothing but absolute blackness, and blocking out all further enquiry.

EXAMPLES 6 and 7 are my Madeira observations; the one excellently confirming the other, and showing over the whole extent of the group nothing but the clearest and most admirable of distinct and sharp, though thick, spectroscopic lines. Two wide doubles, a treble, a wide double, a close double, and a single line, these constitute the so-called attached band. Then comes what earlier observers have so generally represented as one thick club of a line, more or less hazy, or the real Great **B** line itself; but here it resolves its mass into three close, strong, striking doubles; all of which, excepting only the first, already alluded to in the previous subject, show the bright scarlet skylight of the continuous spectrum between their several lines. The definition was always superb.

The thin lines to the extreme right are apparently Solar; and there I have been able to improve very little on what Kirchhoff and Hofman saw with the most admirably defining large prismatic spectroscope made for them by the house of Steinheil in Munich. Their repesentations of these thin lines appear no doubt very broad and clumsy here; but that is a necessary consequence of their having employed lithographic tint-stones, and made up by breadth for faintness of colour; and then having had that poor substitute for engraving exposed to a magnifying of from 16 to 21 times in breadth. The probable chemical parentage of this grand line-group Great B, and its locality of production will be discussed further on, together with that of the so very similarly structured group Great A.

PLATE VII.—Subject 8.

The Great C line in a "High Sun." The Spectrum colour, a Scarlet Red. The Light now very bright.

This **C** line in the scarlet red of the Sun's continous spectrum, is the well-known Red Hydrogen electric spark line of the chemists, and is one of the most essentially and characteristically Solar of all the Fraunhofer lines. It is even anti-terrestrial: for there is no indication either of it, or of any other known marks of free Hydrogen as a gas in the Earth's atmosphere. But, as I have already remarked, there have been no powerful examinations yet made, such as the world expects from London and its unexampled wealth, of how hydrogen *would* look by pure, cold transmission through a long tube, or in the manner it *would* act, if it were a constituent part of our atmosphere. The line here represented at 38,638 is also a Solar line, but derived from Iron. The others may be all terrestrial, some perhaps air or dry-gas lines, but the chief part of them are produced by watery vapour, as we may have an opportunity of proving in the next plate. Meanwhile,

EXAMPLE 1, of this Plate 7, is Angstrom's view of the Great **C** Hydrogen line in a high Sun. The thinness of the other lines, and the paucity of them will be duly noticed.

EXAMPLES 2 and 3, are the two versions of Kirchhoff's and Hofman's map; they make the **C** line sufficiently conspicuous, insert more thin lines than Angstrom, but blurr them sadly by their tint-printing method of representing them.

EXAMPLE 4, is the beautifully observed, beautifully engraved Map of the distinguished Solar physicist, M. Janssen. But the scale is unfortunately small, and still more unfortunately, shade, or haze is represented (at least so I judge) by thin, almost microscopically thin and close *vertical* lines: except when the said haze is very dense, and then it is crossed by horizontal lines in addition to the vertical shading lines. Hence, though M. Janssen certainly draws *two* thin vertical lines on one side of Great **C,** and *seven* on the other, in such a direction that they might pass simply and independently as just so many separate and clear Fraunhofer lines, I have assumed them to mean nothing but undefined haze, and have represented them by the symbols proper to that kind of obscurity in a fair spectrum view.

EXAMPLE 5, gives no trouble. It is merely the Royal Society's view of this part of the spectrum in a high sun: and shows **C** big enough and black enough for anything, but reveals nothing else whatever through all that neighbourhood.

EXAMPLES 6 and 7, are my Madeira views of this spectral region. The number of thin lines, it will be seen, is increased, their beauty, refinement, and variety enhanced still more; but what is the meaning of the paleness and the haze about the principal line Great **C** itself? Our previous views of all the lines of Great **B,** on the contrary, have shown that every appearance there of haze in older observations is a fallacious effect of imperfect instruments; but here it is our best instruments, and best or highest sun-views, which show the **C** line, most certainly hazy!

The explanation is simply this, that Great **C** is a Hydrogen line; and Hydrogen, anywhere and at all times the most volatile, heating, and combustible of all the gases, is, when in the Sun, perpetually bursting forth in Solar red prominences; shooting out hither and thither with such inordinate and varied velocities (see Professor Young's and Mr Lockyer's direct observations of the same) as, at each of these individual explosions, to alter the place of the **C** line in the spectrum, as supplied from those parts of the Sun, very notably for the time. But as my method of observing was an integration of all the Hydrogen activities going on over the whole surface of the Sun at one and the same moment, this general line in the red, **C,** could have no sharp definite outline or very narrow and black included space. The lines of the Great **B** bands possessed such a character eminently, but that was because they were produced by the quiescent absorptive action of gases at all but perfect peace far from the restless furnaces of the Sun.

Yet why, it may be asked, if the above is the true explanation of the broad, faint, hazy character of **C** in my drawings, did all the previous observers represent their **C** lines so very black, and so well defined?

1st. Because they had not dispersion and magnifying enough to bring out the difference between a narrow black line, and a band broader, but fainter intrinsically; so they took **C** always to be the former; represented it, on their small maps, as a first-class line; and now the magnifying their maps have undergone, has rendered any small error or exaggeration they committed palpably evident.

2nd. The Solar Hydrogen may not have been in so agitated and explosive a condition when they observed, as when I did, last summer at Madeira; and the Sun spot changes, which were daily noted by me in the drawings already alluded to, showed that the Solar activities were then far greater than in several preceding years according to the records then made.

PLATE VIII.—Subject 9.

The Great C line in a Low Sun. The Spectrum Colour, a Scarlet Red.

EXAMPLE 1 shows Angstrom's view of this subject, giving a large increase in the number and strength of the lines, and with much general haze.

EXAMPLE 2, I introduce with reservation, for it has required to be so much magnified to bring it up to the one scale adopted here, that close lines which, in the small original, did really to the eye produce an effect of interstitial shade, no longer do so in the enlarged copy. But the name of David Brewster *should* be kept in grateful, honoured memory wherever solar spectroscopy is concerned; I have therefore tried to partly cure the described imperfection by introducing a little general shading, which I hope will not be objected to. Similarly, also, have I helped, and I trust not perverted, **EXAMPLE 3** from Kirchhoff and Hofman.

EXAMPLE 4 has required the dis-entanglement of some of M. Janssen's real spectral lines from his vertical shading lines; and in—

EXAMPLE 5.—There has been no doubt, that excepting one line only, all the innumerable others, which are an addition in the "Philosophical Transactions" over their high sun-view, are merely the Royal Society's regretable method of representing spectral haze or darkness by close, machine-ruled, vertical lines. Yet, though of no great importance as an absolute spectrum picture in itself, this view by the Royal Society is of eminent service when contrasted with Example 5, plate 7, in showing that something mysteriously powerful in darkness has come over all the neighbourhood of the **C** line between a high, and a low, sun.

EXAMPLES 6 and 7, are my Madeira observations, quite clear of general haze, but showing greatly increased numbers and energy of terrestrial, and probably water-vapour, lines;* and also exhibiting the odd combinations which they sometimes make, or almost make, with true Solar lines wherewith they have physically not the slighest connection. In this category will be noticed the two intruding companions on the left of the **C** line; and the strong terrestrial line at 38,638, which seems to have hid the Solar Iron line at that place in Example 7, or at least made it too close to be separated under the condition of atmosphere, Sun and Spectroscope, in a low Sun view.

* The general places of these lines are connected with water vapour, by noting their increased darkness, as "Rain-bands" in extra humid conditions of the atmosphere, as shown by wet and dry thermometers.

PLATE IX.—Subject 10.

High Sun view of the α (Alpha) band, called also "C 6," by Sir David Brewster; Spectrum Colour, a full Orange. The Light now extremely bright.

In a very high Sun, and with anything less than a most powerful spectroscope, this subject, though at sunset one of the chief features of the red and orange end of the Solar spectrum, is either actually invisible, or at least entirely unrecognisable. In my first visit to Portugal I could not, under the circumstances, see anything certainly different from the vanishingly faint Solar lines which occur at frequent intervals in that neighbourhood; but on the second occasion, with a larger and better apparatus, I was as surprised as delighted, to recognise three minute and faint bands of shade at about two bands breadth from each other; and something so very different from the needle like, mutual-separation character of thin Solar lines, that I made sure it was the noontide embryo of the Sunset α (alpha) band The aspect in the spectroscope was just as if Nature herself had touched in with a finely pointed camels-hair pencil, and a very light shade of Indian ink, three pale narrow bands amongst all the other sharp lines. But when a day of peculiarly fine definition arrived, lo! the band shade was gone, and I saw only two or three ultra thin and close lines in the place of each such band; while since then, as mentioned already on pages 10 and 11, I have come to recognise that such shaded bands are the production on the eye of lines too close to be separated and distinctly seen at the time. But the loss of the band haze of imperfect vision at Madeira did not prevent the embryo alpha band being distinguished: for repetitions of two or three lines, in groups at equal distances apart, is one of the most certain indications of telluric gas bands in Nature's *cold* way.

EXAMPLE 1, or Angstrom's view of this difficult subject, is much assisted by his so-called high sun not having been, on account of his hyperborean Latitude, really very high; and there is no line or band which comes out so regularly and certainly in proportion as the sun descends in altitude as this alpha band: whence it must be produced by one of the permanent gases of the earth's atmosphere; though it is not known what or which it may be, and whether it is, or is not, the place of the red Aurora line.

EXAMPLES 2 and 3, show both of the British editions of Kirchhoff and Hofman's map, exhibiting only faint tint-stone lines over all the region; and also claiming one of them, in the very place of the embryo alpha band, as produced by *gold*—Solar gold of course. Now, as these eminent physicists knew well enough that the great alpha band of Sunset is nothing bnt terrestrial atmospheric effect, I could only imagine at first that their Au. must have been a misprint for Aer; but, on referring to the standard spectroscopic lists of gold amongst the chemists, I find that there are not only gold lines in this neighbourhood, but that one of the chief lines of gold falls on the very place of the centre of intensity of this band. Yet that circumstance probably proves too much, for were the Sun to show a strong gold line in the place of this atmospheric Alpha, there ought to be, at 43,515 and 48,565 W.N. Place, much stronger lines of the same physical origin; but nothing of the kind has yet been recorded in any of the most approved Solar spectrum maps.

EXAMPLE 4, is M. Janssen's better engraved view; and

EXAMPLE 5, the Royal Society's second attempt to represent the region, and show whatever is representable there.

EXAMPLES 6 and 7, are my Madeira observations with the Rutherfurd Grating, which has more power in bringing out the thin, well defined lines of this red-orange region of the spectrum than any prisms I have yet had the fortune to employ. Here, accordingly, in a space where the Royal Society has mapped only three lines, the grating showed 40, and many of them, as those between 40,430 and 40,475 W.N. Place, arranged in doublets or triplets, which spoke at once of the presence of a telluric gas band: and yet so infinitely weaker than the, by many persons, equally supposed telluric gas bands of Great **A** and Great **B**, that they, at all events could hardly have been prepared by theory alone, for what was coming at a lower altitude of the Sun.

PLATE X.—SUBJECT 11.

THE a (ALPHA) BAND IN A LOW SUN, CALLED ALSO "**C 6**," BY SIR DAVID BREWSTER. COLOUR, A FULL ORANGE.

EXAMPLE 1, shows the terrible strength and blackness with which Angström saw this remarkable band near Sun-set.

EXAMPLE 2, is introduced with much reservation, and for memorial purposes only, from the descriptions as well as the engraving contained in Sir D. Brewster's and Dr Gladstone's paper of 1860.

EXAMPLE 3, is somewhat similarly introduced to keep Professor Kirchhoff and M. Hofman favourably in mind, for their day.

EXAMPLE 4, is the much advanced drawing and engraving of M. Janssen, showing, especially when compared with his high Sun view, how the lines have multiplied and strengthened, and haze bands started up in his Low Sun view.

EXAMPLE 5, is similarly to be compared with its author's own high Sun view, and the growth of lines and bands becomes immediately undeniable.

EXAMPLES 6 and 7, are my Madeira views with the Rutherfurd Grating, in the lowest sun I could obtain there: and behold, there was no haze that was not resolvable into the most exquisitely sharp and well defined lines; but these lines were so very much increased in number and positive blackness, that their telluric origin is not only confessed, but published and insisted on thereby. And if, during the still prevailing dearth of proper experimental enquiries by the great Societies of London, the question be repeated as to *what* telluric gas may be the cause of the band,—I may perhaps mention that I have lately (November 1881) discovered a configuration of the lines in the low temperature electric spectrum of Oxygen, quite different from those of Nitrogen, but having a strong family resemblance to the bandelets of lines in this mysterious a (alpha) band. (Trans R. Soc. Ed. 1880-1.)

PLATE XI.—SUBJECT 12.

THE **D** LINES IN A HIGH SUN. SPECTRUM COLOUR OF THE REGION, A FULL YELLOW. ITS LIGHT A MAXIMUM; QUITE GLORIOUS.

EXAMPLE 1, or Angstrom's view of this subject is singularly clear, and besides the two great "**D**" or Solar Sodium, *i.e.* Na, lines, shews only true Sun lines throughout; the Nickel line between D^1 and D^2 being a particular and classical instance of optical intrusion, in the more generally celebrated case of the **D**, or "Salt," lines themselves.

EXAMPLES 2 and 3, or the two British versions of Kirchhoff and Hofman, show many faint lines in addition to Angstrom's, and they are probably the enterings upon the scene of watery vapour's lines, all represented in merely tint-stone colours.

EXAMPLE 4, is the best rendering I can make of M. Janssen's most careful engraving; but where double and treble thin vertical lines, are too evidently no more than the engraver's microscopic method of giving sufficient breadth, but not too deep colour, to single Fraunhofer lines.

EXAMPLE 5, by the Royal Society in 1875, is very much like Angstrom's view in 1868, but with the addition of a decided water-vapour line between the Nickel line and D^2.

EXAMPLES 6 and 7, are my Madeira views, which in addition to Angstrom's 6 Solar lines, show 19 other lines whose origin is believed to be telluric watery vapour; and which cannot be got rid of, even in the highest summer Sun, of the *Madeiran* climate. The physiognomy however of the **D** lines, is peculiar and no doubt truly Solar. First, though a great deal darker than the great **C** line, see plate 7, they are not quite black, which is sought to be represented here symbolically by shortening the dark column; and next, there is a haze about them, not so extensive, or dark, as that about **C**: whence we may safely draw the conclusion that Solar Sodium (NA. of the chemists) enters into the composition of the Sun's out-shooting red prominences, but not to the full extent of the Hydrogen manifested by the **C** line.

PLATE XI.—SUBJECT 13.

THE **D** LINES IN A LOW SUN. SPECTRUM COLOUR, A FULL YELLOW.

EXAMPLE 1, shows Angstrom making up abundantly for no telluric lines in his high Sun Spectrum, by showing them now in egregious force, and accompanied by terrifically strong haze bands.

EXAMPLE 2, is introduced with reservation, and for memorial purposes chiefly, being compounded out of descriptions, rather than drawings, by Sir David Brewster chiefly.

EXAMPLE 3, is similarly prepared from descriptions as well as drawings by Professor Kirchhoff, and is chiefly memorial to his name.

EXAMPLE 4, is the best compromise I can make between the vertical lines engraved in M. Janssen's map for Fraunhofer lines, and the innumerable others intended apparently only for haze. The same is the case with **Example 5,** or the Royal Society's view of this subject. But they are neither of them to be weighed for their absolute pictures of this one subject alone, but rather to be compared with their rendering of Subject 12, and the *difference* therefrom to be gratefully noted; when the tremendous increase of telluric effects, whether of water-vapour, or any other, lines and haze become worthily apparent.

EXAMPLES 6 and 7, or my Madeira observations, confirm the above in the great increase in both the numbers and intensities of the telluric, or rather as we may here safely call them, Water-vapour, lines,—but declare that there need be no undefined haze over all the field, with a really good spectroscope,—the purely Solar haze about the **D** lines being of course excepted; as well as the very minute feature of a bandelet of lines at 43,057 W.N. Place not fully resolved.

PLATE XII.—Subject 14.

The Helium group in a high Sun. In the Citron-green colour of the Spectrum. The Light very strong.

In the continued progress of our subjects from the red, to the violet, end of the Spectrum, we have now left behind all the red, orange and yellow, leaving with them nearly every well-known telluric line, whether of watery vapour or dry gas, and have entered the green; wherein, and whence forward to the violet, there is seldom anything but one true solar line, after another, to be seen, except at about 50,400 W.N. Place, where Angstrom notes a band which he says is strong in summer.

But at our present Spectrum-place of 47,778 W.N. Pl., something more important demands our attention. In the year 1870, 71, and 72, the Eclipse observers noted a particular green spectral line in the chromosphere and Corona of the Sun, which line was also the only visible line of all the outermost and faintest of the Solar envelopes. They even thought they detected the same line in the Aurora and in the Zodiacal light; and finding an iron line in its apparently exact spectral place, in the maps, both Solar and chemical, of Kirchhoff, Angstrom and Thalen, they called the cosmical green line they saw everywhere an *iron* line; and considered that some vapour of iron must be universally distributed and form a gas lighter still than hydrogen, because extending further away from the Sun's surface than that exceedingly light gas.

But many other persons soon remarked, that the chemical iron line in question was by no means one of the strongest lines in the iron spectrum; therefore why should it be the only one manifested in those almost extra solar regions, if iron were really there; and at length it was reserved to Professor Young, of Princeton, U.S., America, to demonstrate in his exact and convincing manner that in the Solar spectrum, there were really two lines in that place, but so very close together as to require exceeding dispersion power to show them separate; one of these was the very moderate iron line originally noted there in chemistry, while the other was the newly observed mysterious substance met with chiefly outside the Sun (provisionally now called "Helium"), and not having necessarily any relation whatever with iron.

EXAMPLE 1, shows Angstrom's view of this subject, where at 47,778 he has only one line, and that was marked by him "iron;" the additional name Helium, as it appears on the paper, having been added since by me.

EXAMPLE 2, is Professor Kirchhoff's view of the same really combined line, but also representing it single.

EXAMPLES 3 and 4, are the Royal Society's views in both high and low Sun, of all the region of, and near, that peculiar line or pair of lines, but showing nothing whatever therein.

EXAMPLE 5, introduces a new authority, with whom we shall have much to do in all the remainder of our work. He is the learned Professor Vogel, of the *Astro-physicalischen* Observatory at Potsdam, Prussia; his spectroscope was prismatic, and vastly more powerful than either the grating of Angstrom or the prisms of Kirchhoff; and his map of the Solar spectrum, so far as it goes; viz., from 47,000 to 65,000 of W.N. Place, or from the Citron green through blue and violet to lavender, is on three times the scale of either of those older and hitherto standard productions. Kirchhoff's prisms were 4 in number, of simple white flint glass, of 45°, and 60° refracting angle, and had a separating power of barely 16° between **A** and **H**. But Vogel's, as I gather from M. Perrotin's recent book on Observatories, were six *Rutherfurd prisms*. Now each of these is a compound of 2 dense prisms of 90° refracting angle, and 3 light anti-prisms; so that with small "deviation" of the transmitted ray, it possesses immense "dispersion," or separating power of the same; probably equal to 4 simple prisms of 60° in white flint. Wherefore the whole 6 must have a power of no less than 24 ordinary prisms, and disperse the spectrum through more than 100° between **A** and **H**. Professor Vogel then is a giant in the subject; and as he kindly presented me with a special copy of his map just before I left for Madeira, I am doubly bound to report how I found it.

The Map, as published, is unfortunately an affair of lithographic printing from tint-stones; but the lines themselves are so neatly and thinly put in there, and are submitted to so little magnifying by me on account of their originally large scale, that I have not found it necessary in my rendering of them, to indicate their characteristic look in any other way than thin lines of different heights; except indeed in a few crucial cases, and the "Helium" line is one of these.

Looking then at that line at 47,778 W.N. Place, as drawn by Professor Vogel, we see a strong black line at the spot, and there is also a tint-stone line sticking out on one side of it. Now what was that intended to represent? Strictly, as it stands, it can only be a faint haze on one side of the black line. But again tint-stones are very treacherous for their misplacements, and the faint line might have been intended by Professor Vogel to stand just clear of the black line, and so to form with it a close double. Some miscarriage in printing of the same kind seems also to have occurred with the strong groups at either end of the strip of spectrum represented on this Plate, and, as we may appreciate better on considering the Madeira view in—

EXAMPLE 6.—There, the admirable definition of Mr Rutherfurd's grating exhibited to me at 47,778, a clear, clean, beautiful *double* line, of very nearly equal strength of lines. While at each end of the whole strip, was a most remarkable triple; at the left hand end, a thin line between two thick ones, and at the right hand end, a thick one between two thin ones. The symmetry and beauty of these two groups of powerful lines is rather lost in Professor Vogel's map; but on the other hand, I have the pleasure of noting, and shall have to note it all the way through, that he sees many more thin lines than I do.

EXAMPLE 7.—This picture is derived from the new and magnificent Solar Spectrum-map by M. Fievez of the Royal Observatory, Brussels, in 1882; alluded to already in the note to page 3, col. 2; and further to be described towards the close of the next subject; *viz.* "the Great **E** group."

In the meanwhile it will probably be regarded as a more powerful representation than my own, both for thick, and thin, lines. Wherefore its confirmations, if any, must be most valuable, of matters seen by me more or less questionably, because in opposition to, or possibly advance of, all my then known predecessors; —as the plate itself will show at a glance, far more easily than a written description.

PLATE XIII.—Subject 15.

The Great E group.—In the Citron-Green colour of the Spectrum; and in excellent, strong light.

This so-called "line" of small spectroscopes consists here, as shown in **Example 1**, or the magnified view from Angstrom's Normal Solar Spectrum, of four grand double lines decreasing both in strength, and width apart, towards the right, and preceded by three notable single lines on the left. The above doubles, though ranged on an almost symmetrical system, are largely accidental, being composed variously of here an iron line, there one of calcium, or of cobalt, and then of iron over again.

EXAMPLE 2, from Kirchhoff and Hofman, very nearly confirms Angstrom's view, with the addition of singling out the particular double whose centre is in W.N. Place 48,205, as the strongest of the whole group beyond compare, and therefore *par excellence* forming the **E** line. It is consequently with much surprise that we find in—

EXAMPLE 3, that the Royal Society, London, six years later, makes the double there faint and thin in a high Sun; and though somewhat thickening it in a low Sun (see "Philosophical Transactions" for 1875), yet does not bring it up even there to the strength of the second double of the series, in W.N. Place 48,242. But on turning to—

EXAMPLE 4, or Professor Vogel's recent view of the whole group, we not only find the predominance of the 1st. double at 48,205 W.N. Place, re-established, but a host of other most interesting accuracies comes out.

The three leading single lines, for instance, of his predecessors, turn out to be, each of them, a rather close double; the second line of the great **E** double is shown to be attended with much haze (misplaced perhaps to one side by the weaknesses of tint-printing), and there are 13, in place of only 1 or 2, thin lines.

But **EXAMPLE 5** shows that not even Professor Vogel, with 6 Rutherfurd Hamburgh prisms in 1880, can stand before Professor Young with a Rutherfurd Grating in 1881; for he, Professor Young, splits up three of Professor Vogel's single lines into doubles, turns one of his doubles into a triple, adds four cases of physical characteristic as to haze, and increases the number of thin lines up to 27. It is indeed, a marvellous feat in spectroscopy, this **E** group of Professor Young of Princeton, U.S., America; matchless for combined qualities of eye, hand, and instrument.

Though doing my best with thin and sharp steel pens to make an etching-copy, in black lines on white, of Professor Young's very refined drawing in pencil of this group, and with the distinct *proviso* of the symbolical principles of spectrum drawings laid down at p. 6, c. 2, being included and accepted,—still I was not entirely satisfied that I had done justice to the original. But when the photo-lithograph proof of the drawing reached me, there was no longer any doubt that some improvement must be made. On *then* comparing the whole of the photo-lithographs with their respective Manuscript originals, the lines were found to be slightly broadened and roughened too along the edges. With single solitary lines that did not much signify; but it was fatal to the transparency of shadows put in by close, hatched and crossed lines, for it often blocked them up, parts of them with absolute black. Even this, however, private economy might have led me to put up with; but that the almost infinitely close, yet clear double of Professor Young's drawing at 48,258 W.N. Pl. should be clogged into a broad single line, could not be tolerated. After some conversation with Mr Johnston as to where, in the photo-lithographic process the broadening of the lines had had its origin, the glass negative taken in the Camera was brought, and I instantly saw that it was there. For the case was quite a similar one to those described on p. 10, col. 2, connected with the filling up of the interstitial spaces of the stronger doubles in Angstrom's eye-view of **B**; *viz.* though the lines were fairly sharp on their outer sides, their inner edges closely approximating *had thrown out haze towards each other.*

So a new negative, with smaller stop on the lens, was prepared of Plate XIII.; and in it will not only be seen Professor Young's very close double, clearly represented; but the sharpness of all the lines, and greater transparency of the closely etched shadows will be found an improvement on the similar features of all the other plates,—if the difference which I now see in the proofs, shall be kept up throughout the required 500 impressions for the book.

EXAMPLE 6, or my own Madeira observation is not equal to Professor Vogel's for thin lines, but better than his for several details of the thick ones; giving for instance with great force the one-sided haze of the first member of the first double, the triplicity of Vogel's second double, the haziness of several other lines, and still more clearly the duplicity of Vogel's single line at 48,246. But I could not come near Professor Young in splitting the first Member of the great **E** double, or the first member of the last double but one, though I tried very hard so to do. Whether eye, or atmosphere, or heliostat, or objectives were each and all rather below *par*, I do not know; but I am rather inclined to focus the chief doubts on the grating; for, admirable though that was in both the first and second orders of spectrum, and with magnifying powers from 20 to 60 on the telescope of inspection, yet whenever I tried more separation power by using the third or fourth orders of spectrum, and eye-pieces above 60, *all* the lines in view became optically hazy, and more was lost by bad definition than gained by angular extent of separation.

When it was so very easy at any time, by overstraining the powers of the spectroscope, to make any lines look hazy, great caution was necessary to assure one's-self in each case of haze being entered in the drawing, that it was cosmical haze, marking a physical characteristic of that portion of glowing gas in the sun, and not an optical imperfection in the observing room. I hope too that such care *was* always taken, though one minute form of occasional error may remain, in cases where a very close double line was not quite within the power of vision. For sometimes when such a line, more or less broad, pale and hazy, would, by better focussing or otherwise, just come *within* the limits of resolvability, it would at that moment start into a clean, black double as if by magic, and so remain as long as the definition was good. Hence, if I could have in any way split the faint, hazy lines at 48,200 and 48,258, I have little doubt but that I should have seen them as neat and clean as Professor Young did; but all that I could do towards it, was, on a subsequent occasion to believe that I saw the material of those lines rather paler than others; an appearance which is symbolised in Example 6 by the shortened length given to the two.

EXAMPLE 7.—Comparing here M. Fievez view first with Professor Vogel's (Ex. 4), we find it on a *par* as to representation of thin lines, but much advanced in the separation of close doubles of thick lines, witness the two at 48,238 and 48,261; these places being those they appear under in M. Fievez drawing and seem to require a correction of—3 units to reduce them to most of the other examples;—though with none of them, as represented by me, is extreme correctness of absolute place the cynosure aimed at.

This desideratum is, the physical character of the lines; and we now come to compare M. Fievez work with Professor Young's. Seeing that Prof. Young used a Rutherfurd Grating alone, while M. Fievez superadded to exactly one of these gratings, of the same size and with the same number of lines to the inch, two of Astronomer-Royal Christie's celebrated half-prisms of dispersion announced to be equal to 11 prisms of 60°,—we might expect that there was no hope for the former. But in the matter of thin lines, Prof. Young has 27, where M. Fievez has only 13. In the matter of strong lines split into two, Prof. Young has one more, viz., the very important left hand number of the principal pair of Great **E** itself. In the matter of doubles shown to be triples Prof. Young has one (confirmed by myself) which M. Fievez has not, at 48,156 W.N. Place, and finally Prof. Young has a one-sided haze on the first line, and a double sided haze on several others (all confirmed by myself in Ex. 6) of which there is nothing whatever in M. Fievez view.

This absence of all haze is very remarkable in Ex. 7; and still more is the fact of all M. Fievez' doubles, being, whenever seen as such at all, more widely separated than the same lines in Nature as observed by other persons, whether Prof. Young, Prof. Vogel, or myself; and whether in this Subject 15, or any other wherein he is quoted, from Subject 14, Plate XII., to Subject 20, Plate XVI.

PLATE XIII.—Subject 16.

The Bandelet of lines following E. In the Citron-green Colour of the Spectrum. The Light strong.

After the experience of observing the exquisitely rhythmical bands of lines preceding great **A** and great **B**, I was induced to attach exceeding importance to any symmetry of like kind connecting together any two or three of the usually divergent and antagonistic lines in the more Solar and refrangible part of the spectrum. The present case of such a symmetric conjunction of several lines at or near 48,340 W.N. Place, though it lies so close to great **E**, that Professor Young would have been certain to give a good account of it, had his map extended so far,—is unnoticed in any of the authorities I have had the opportunity of consulting; as thus—

In **EXAMPLE 1,** Professor Angstrom shows in that place merely one thick, and one thin line.

EXAMPLE 2, Professor Kirchhoff gives one tint-stone bar.

EXAMPLES 3 and 4, the Royal Society, London, therein gives nothing whatever.

EXAMPLE 5, Professor Vogel gives one thick line and two thin ones of equal character; but in

EXAMPLE 6 may be seen the exquisite gradation which appeared to me in Madeira on every occasion on which I examined this object, viz., one thick line, three graduated thinner lines, and then a haze band which might have contained two others thinner still.

EXAMPLE 7, shows M. Fievez treatment of the subject; remarkable for its many thin lines, and wide separation of the last double.

PLATE XIV.—Subject 17.

A "Basic" line preceding "little b;"—in the full GREEN colour of the Spectrum.

On examining the spectrum still further on than our last subject, I perceived at 48,775 W.N. Place a very close double line; and on turning to Angstrom's trusty map of references, found it was one of those reputed single lines of his, which has been declared common to two different bases or chemical elements, in this case Chrome and Iron, see **EXAMPLE 1.**

EXAMPLES 2 and 3, show that Professor Kirchhoff saw something more than one strong line; but what it was, and on which side of the thick line, the uncertainties of tint-stone printing have thrown into doubt. In—

EXAMPLE 4, the Royal Society's "Philosophical Transactions" throw no light on the question. And even in—

EXAMPLE 5, Professor Vogel, though he enriches the whole field magnificently with thin lines, and delineates a shadow on the further side of the particular line in question, yet gives no indication of its being a double; and, least of all of the very distinct order shown in—

EXAMPLE 6, or my Madeira observation. I would also there call attention to the symmetrical gradation of the three strong lines commencing the group, as being a real and important feature not noticed before. Angstrom attributes the one line which he has in their place to *iron;* and it might be well worth while for those who have apparatus for examining the high temperature electric spectrum of iron, under very considerable dispersion, to ascertain whether the iron line at that place is single, as usually represented, or is an embryo band of graduated lines like those exhibited by the Sun.

EXAMPLE 7, is M. Fievez' drawing of the same region; very powerful and very full.

PLATE XV.—Subject 18.

The "Little b" group, in the full Green Colour of the Sun's continuous Spectrum. Light fairly strong.

After Fraunhofer had spaced out the Solar spectrum into approximately equal parts, by their nearest strong lines, and named those with the capital letters of the alphabet from **A** to **H;** he then went over it again, and named any notable residual lines by the small letters of the alphabet; whence it came, that our present group of lines, stronger and blacker than all the great lettered lines immediately before and after it, is known as "little **b**;" but anything serves as a mere name, to those who research into the *nature* of any fact, if the said name is universally and and similarly accepted amongst all physicists; and that we believe is eminently so in the present case.

EXAMPLE 1, shows Angstrom's view of this subject. There are many small Iron lines in the field, but its chief characteristic is three great Magnesium lines, forming $\mathbf{b}^1$, $\mathbf{b}^2$, and $\mathbf{b}^4$; $\mathbf{b}^3$ being a basic line of Nickel and Iron. Further, $\mathbf{b}^1$ and $\mathbf{b}^2$ are notably hazy-edged, while $\mathbf{b}^4$ is clean and sharp, though of the same material as $\mathbf{b}^1$ and $\mathbf{b}^2$; or rather of their Magnesium, with Iron added. We shall return upon this point presently.

EXAMPLE 2, is a very great triumph for Sir David Brewster and Dr Gladstone in their early day; for they show the chief features of the group; and, while from $\mathbf{b}^1$ to $\mathbf{b}^3$ is rather more than twice the distance of the classic **D** lines apart; the distance from $\mathbf{b}^3$ to $\mathbf{b}^4$ is only one-third the **D** line distance, and therefore escaped many of the early spectroscopists. There is no haze shown about any of the principal lines; but there are none of them represented as absolutely black, a condition which is expressed here by the column of the line not being taken up quite to the top of the prepared spectrum strip.

EXAMPLE 3.—This is the **b** group by the Royal Society in 1875.

Interpreting their closely ruled vertical lines to mean haze, then they represent haze on either side of $\mathbf{b}^1$ and $\mathbf{b}^2$, but none about $\mathbf{b}^3$ or $\mathbf{b}^4$; and they further engrave those lines as pale in a high Sun, but dense black in a low Sun, as though they were telluric lines; in which conclusion however, no other known authority agrees with them.

EXAMPLE 4, is in many respects a valuable addition to our knowledge of this subject. M. Fievez, *Astronome-adjoint* of the Royal Observatory of Brussels, is already favourably known by several neat and powerful essays in spectroscopy; and he commenced this subject by examining the chemical spectrum of Magnesium under far more powerful and condensed electric sparks than had been used before his time; whereby he increased Angstrom's three lines of Magnesium to no less than 10. He then examined the solar spectrum with a Rutherfurd Grating, and found that all his new Magnesium lines had their counterpart black lines there. Two of them were even notably hazy, after the fashion of **b**¹ and **b**²; though, curiously enough, **b**⁴ is represented by him as not hazy at all, in spite of its long-established magnesium; while **b**³ he yet represents as hazy-edged, though there is no magnesium in it.

Now no person who has not spectroscoped Magnesium under equally powerful electric deflagration with M. Fievez, can on that account object to the real existence of M. Fievez' new magnesium lines, But seeing that most of them are lines which Angstrom has connected with iron, it would have been satisfactory if M. Fievez had given proof that there was no iron impurity in his Magnesium; while there are some points in his Solar-spectrum view of the lines, which may indicate either an abnormal disturbance and explosion of Magnesium, and other vapours in the Sun at the time of his observation; or they are not quite so accurate as might be desired. Thus—

EXAMPLE 5, by Professor Vogel at Potsdam, almost at the same absolute date, gives us a proof of superior accuracy in simple solar observation at the very starting, by showing the first line, of all the former observers who pictured it at all, to be a neat as well as strong *double* line. We find there also exactly what was to have been expected from the leading chemistry of the case, viz., that if so oxidisable or combustible a metal as Magnesium has its **b**¹ and **b**² lines accompanied by wonderful haze-clouds, **b**⁴ has just as much; though the perversities of the tint-printing method have thrown the mass of the haze on one side of the line. But **b**³, which M. Fievez makes hazy without any magnesium, is straight and clean-edged in Professor Vogel's drawing. Again, the two lines at 49,040 and 49,075, which, according to Angstrom, are the one of Iron and the other of Nickel, and according to M. Fievez, are both of Magnesium, and notably hazy in his sky, are perfectly clean and sharp in Professor Vogel's view.* In—

EXAMPLE 6, or my Madeira view, all the chief features of Professor Vogel's map are confirmed with some further details. The volatility of Magnesium exposed to Solar heat seems abundantly expressed by the portentous haze about each of the old accepted Magnesium lines, viz. **b**¹, **b**², and **b**⁴, as well as by their breadth, accompanied by the paleness of each central line itself, expressed symbolically by shortening the column. The haze is greater than that of Sodium in the **D** lines, but not so great as the Hydrogen of the **C** line; and again, the paleness of the central line is more marked than that of the **D** line, but by no means so much as that of the **C**, or Hydrogen line; whence the degree of volatility of Magnesium is easily placed between Sodium and Hydrogen.

Again **b**³, though eminently sharp-edged, is a pale line giving me inevitably the idea of its being a very close double; and it may be in *that* way, or it may be by the closely following line, that it militates against the idea of Angstrom who did not see any such companion, that it is one line standing for two metals, viz. Nickel and Iron.

* Since the above was written, M. Fievez has prepared for himself a more powerful spectroscope, and tells me that he has found the two lines are not hazy.

But, in **b**⁴, we have something still more curious, for the central line appeared to me there double, and in that case it accounts, apparently at once, for Angstrom's attribution of its origin to both Magnesium and Iron.†

EXAMPLE 7.—Here M. Fievez, in his large map of the present year, has done himself admirable justice; for his **b**¹, **b**², and **b**⁴ are all properly hazy; while his two strong lines between **b**¹ and **b**², are not hazy at all; neither is the **b**³; while both that, and **b**⁴ are truly doubled; and several thin lines beyond other observers (doubtless real), are introduced.

† Since the above was written, I find that this duplicity of **b**⁴ had been independently noted by both Professor Young with a grating, and M. Thollon with very powerful prisms.

PLATE XVI.—Subject 19.

A group following "little b," in the Green Colour of the Spectrum. The Light not too strong.

This subject includes no less than 3 basic lines of Professor Angstrom; Iron and Nickel in every case, as to be seen in—

EXAMPLE 1, at 49,362, 49,397, and 49,450.

EXAMPLE 2, shows that the last of the three was easily split up by Professor Kirchhoff, and all who have followed him, into two: but the others are untouched.

EXAMPLES 3 and **4**, show the Royal Society abolishing all the earlier lines of the group, and adding telluric effects to the later—in which proceeding they have not been followed as yet by any one else.

EXAMPLE 5, shows the able Professor Vogel doubling and supplying haze to the first basic line at 49,362, supplying haze but nothing else to the second basic line at 49,397; very notably doubling a strong Iron line of Angstrom at 49,430; and of course, doubling the last basic line at 49,450.

EXAMPLE 6 shows my Madeira observation, confirming every one of Professor Vogel's points, but with the addition of trebling his double in the centre of the strip, viz., at or near the place 49,397; in so very signal a manner too, that I can hardly imagine him not to have seen the fact, and can only suppose he intended to represent it by the tint-stone method, but that that ill-omened contrivance, as usual, failed him at his critical need.

EXAMPLE 7, M. Fievez here, besides showing many thin lines of his own, represents my triple; but so broadened out, that I scarcely recognise it.

PLATE XVI.—Subject 20.

The Great F line, in the Glaucous coloured region of the Spectrum. The Light sensibly weaker.

This grand line, caused by Solar Hydrogen, is in several respects a sort of half-way station in the spectrum, a signal post to mark where eye-observation begins to fail, and ordinary silver iodide photography commences to show its remarkable powers; a neutral colour region too, where some would pronounce the colour of the continuous spectrum back-ground to be green, while others equally confidently pronounce it blue, though it appears to be really between the two, or glaucous. The place of this line's appearing, 52,255 W.N., is far past the most brilliant portion of the Solar spectrum, which is rather between **D** in 43,000, and **E** 48,200, W.N. Place, whether seen in Gratings or prisms. But when we examine the luminous spectra of various gases at night, the superior brilliancy of this **F** line, or Hydrogen β (which is usually present in every tube of every terrestrial gas), to anything in the above-mentioned citron and green regions to the left, and anything also in the blue and violet spaces to the right, makes it the summit of the whole of the phenomena for eye-brightness. While on the other hand, for photographic brightness, through *glass* lenses and prisms, the *violet* Hydrogen line is just as superior to this *glaucous* line, as this line is to the violet, when seen by the eye. For proof see Mr Rand Capron's laborious and abundantly illustrated book, entitled "Photographed Spectra," published by E. and F. N. Spon, London, 1877.

Hence it would appear that Professor Vogel, who, in his grand map of the more refrangible half of the spectrum, employed the photographic method *in glass* (for in quartz or Iceland spar there is a very different result), and began with this **F** line, or close to it,—must have made the latter end of an unpublished set of his eye-observed maps of the less refrangible half of the spectrum, include this **F** line also;* whence we have the inestimable advantage of seeing how the eye on one side, and photography on the other, treat one and the same spectral region on their mutual confines.

EXAMPLE 1, shows Angstrom's treatment of the region, indicating, besides the great hazy hydrogen line, 7 others, of which he was able to assign no less than 6 to their originating elements.

EXAMPLE 2, by Professor Kirchhoff, nearly doules the number of lines, but removes the haze from the principal one; while—

EXAMPLE 3, by the Royal Society, slightly increases the lines in number, and re-adds the haze on either side of the Hydrogen line.

EXAMPLE 4, by Professor Vogel, with eye observation, very greatly increases the number and beauty of the smaller lines, and would have added haze on either side of the great **F** line, but that his treacherous tint-stone slipped, and put it on one side.

EXAMPLE 5, also by Professor Vogel, but deduced from his photographs, has the haze about the **F** line properly placed, has very many faint lines, though not quite so many as the eye-method; and all of them are widened, as if taken with too broad a slit.

* Of eye-observed spectrum, Professor Vogel publishes 6 strips extending from 47,000 to 52,950 W.N. Place; while, of Photograph-deduced spectrum, he gives 10 strips, extending from 51,930 to 65,200.

EXAMPLE 6, or my Madeira work, is more like Professor Vogel's eye observations, though his were obtained from prisms and mine with a grating; but they have two refinements which I would beg leave to point out, because I confirmed them again and again at the telescope; thus, **(A)**, The double line at 52,318, in place of being so very unequal as Professor Vogel has rendered it, is a symmetrical pair; and **(B)**, the paleness of the material composing the **F** line, is as notable and interesting a physical proof of its gaseous hydrogen nature, or of the habitudes of Hydrogen in the Sun, as is the wide-spread haze outside it.

EXAMPLE 7.—At this point of the spectrum M. Fievez begins to lose his late capacity for a superior number of thin lines; and his truly grand map, which began with the **C** line, does not reach our next subject **G**, but terminates half-way between that and this present line we are discussing **F**; yet a magnificent contribution it is to an exact knowledge of all the brightest part of the Solar spectrum as seen by simple optics with the eye.

PLATE XVII.—Subject 21.

The "near G" line, or Violet Hydrogen; between the Deep-blue and Violet Regions of the Sun's Continuous Spectrum. The Light is here painfully weak.

While I would agree with Professor Vogel in making the **F** line the point where photographic spectroscoping should begin, although it may not be there quite equal to what the eye can do, there is no reason why eye observations may not considerably overlap that point towards the violet end; and indeed, with some prisms of white flint glass, a very great deal can in that region be done. But with gratings on speculum-metal, to which I was confined on the present occasion, there is a lamentable weakness in their reflected light, as well as a sad contraction of their scale for dispersion, both in, and still more beyond, the blue and violet. Little or nothing, for instance, could I make out further than the great Manganese line, called "little **g**," at 60,100 W.N. Place.† But that is beyond great **G**, the iron and titanium group of lines at 58,967 W.N.; while on this side of great **G**, and therefore by so much nearer to the range for good grating vision, is situated the notable Hydrogen line already alluded to, known as Violet Hydrogen, and Hydrogen γ, among Chemical and Electrical observers of bright line spectra; but as "near **G**," *i.e.* "near great **G**," by Solar spectroscopists. I was anxious moreover, to ascertain whether Mr Rutherfurd's fine example of a grating, though now so near the end of its practical range, could yet detect a hydrogen line in the Sun, by those peculiar physical aspects, which it had so success-

† I can hardly but attribute the extinction of the further violet portion of the spectrum, in large part to the effect of the watery vapour so abundant in the climate of Madeira; and it makes me attach more importance than ever to the Teneriffe Astronomical experiment, and its ascent into a drier, thinner, more transparent, air, being resumed by some one better furnished than I was 25 years ago, or have been ever since.

fully elicited in the case of both great **C**, and great **F**, or Hydrogen α and Hydrogen β; but I determined also to make this trial on Hydrogen γ, the concluding subject of my Madeiran Spectroscopy. Accordingly—

EXAMPLE 1, gives Professor Angstrom's view of this Hydrogen line and neighbourhood—most creditably for his instrument and epoch; yet having the field rather thinly occupied. Violet Hydrogen itself, too, he renders as positively black; though hazy edged on one side, and on the other attached to a very definite breadth of haze of a probably different chemical origin, as he signalises therein lines of both Chromium and Titanium.

EXAMPLES 2 and **3**, show Professor Kirchhoff increasing the number of lines in the field of view greatly; but representing the Hydrogen line by absolute black, and in the second instance without any mitigation of the sharp edges thereof by the attached lines and spaces of tint-stone printing seen in the first example.

EXAMPLE 4, is a most interesting document, being derived from a prism-formed spectrum photographed in the earlier years of spectrum-analysis, by L. M. Rutherfurd, Esq., of New York, the Amateur-maker subsequently of the magnificent gratings wherewith half of his countrymen have accomplished most of their spectroscopings; and with one example of which, all my present Madeiran work has been performed. I had not, however, Mr Rutherfurd's actual photograph to copy, only a lithograph which he had had executed in Berlin, during a European tour. The lithograph was however, commended by him, and is executed with both pen and chalk on a single black-printing stone, so that it has none of the weaknesses of tint-stone work; and it has taxed all my powers of pen and ink etching, to give an idea of its various shadings as well as positive lines. The Hydrogen line, it will be remarked, is grandly conspicuous by excess of outer haze, though its own inner material is absolutely black; but the whole spectrum strip gives a striking idea of that pictorial richness of shading which one sees in the violet regions of the spectrum when well formed, or reproduced in good photographs: and which the late Padre Secchi demanded should be published more frequently, rather than the mere "skeletons of spectra" which usually characterise the eye and hand drawings of most of the learned astronomers.

EXAMPLE 5, shows Professor Vogel, with his grand, compound, Rutherfurd-prism-spectroscope and photography in the new Astro-physicalischen Observatory at Potsdam, to be a master of definition, and of everything necessary to bring into clear view any spectral lines, when such lines are there. But he suffers severely from the crudeness of his tint-stone methods of reproduction and multiplication; his Hydrogen line, though properly haze-bordered on either side, is of absolute blackness; and his slit would appear, from the thickness of all his lines, to have been opened rather too widely.

EXAMPLES 6 and 7, show the Rutherfurd Grating capable still of much of its distinguishing refinement in the representation of lines, neatly, thinly, and yet forcibly when required. Innumerable varieties of shade are distinguished, crossing the length of the field of view. Angstrom's region of haze, on the right hand side of the Hydrogen line, is brought out as conspicuously, and perhaps more explanatorially, than in Mr Rutherfurd's photograph,—while above all the other examples and authorities, the physical nature of Hydrogen is shown at last by the greater breadth, but very much decreased intensity of the shade, of the line itself, belonging to that most light and inflammable of all the gases. But for number of lines at this part of the Spectrum, and thenceforwards the palm is entirely with Professor Vogel.

PLATE XVIII.—

Colours as observed, in both Single, Double, and Triple, Spectra, either super-imposed or mixed.

The arrangement of the Madeira diffraction spectroscope, chiefly for ultra accuracy of line observation, served well also to set forth that exquisite natural index to different *places* in the spectrum, *viz.* Colour: and this was largely because, in place of trusting to the usual impurely coloured glasses, or "shades" to separate special parts of the spectrum for suitable observation, I invariably employed a large prism of white flint glass, and separated the colours, preliminarily to their entering the slit, by that prism's dispersion action alone.

When the light from the slit was still further analysed by the action of the grating, the several distinguishable steps of colour in the continuous spectrum of a bright, and nearly Zenithal Sun, appeared far more numerous, and much more worthy of note, than has been generally recognised heretofore. In fact there seemed to be almost as many successively, and very sensibly different colours existing in the Solar spectrum (when made ultra pure by passing the light through the narrowest of slits), as there are easily appreciable breadths of space in that spectrum. The colours, unfortunately, are not, indeed, so absolutely constant in spectrum place as are Fraunhofer lines; for they (the colours) seem to be endued with certain extents of locomotion in the spectrum, according to the brightness of the light at the time, and the state of the eye. But still these ranges of locomotion never change the appearance of a colour from one side of the spectrum to the other, but only produce certain small variations of + or − on the standard colour at, and for, that place; teaching us therefore to catalogue the places of colours not so much by a definition, as by a type; not mathematically by outer limits or boundaries, but in the natural history method of indicating the whereabouts of each acknowledged centre.

After making many observations in this manner, both in Madeira and in Portugal, I have subsequently arranged the results as in the Table below; where the first column gives the tri-partite division of the Spectrum; the second the 19 names decided on, after weighing the respective merits of optical, artistical, and popular names of colours. The third column gives the W.N. spectrum place of the usual centre of each of such coloured spaces. The fourth column mentions any strong Fraunhofer line in the Sun's continuous spectrum, near such coloured centre; and the fifth column gives the strongest and most easily observed of chemical flame, or electric spark, bright lines near the same W.N. Places in their respective discontinuous spectra. Such bright lines therefore show very nearly the same colour, in each case, as that particular part of the back-ground of the Solar continuous spectrum itself.

SINGLE SPECTRUM COLOURS, IN THEIR NATURAL ORDER.

Tripartite Division of the visible, optical, Spectrum.	Colours by Name.	Central W.N. Place of each Colour.	Solar lines nearest there-to.	Chemical lines nearest there-to.
Red Beginning	Ultra Red	28,000	**X**	Rubidium chloride in flame
	Deep Red	32,000	**Y** and **A**	Potassium α
	RED	36,000	**a** and **B**	Tube oxygen line
	Scarlet Red	38,000	**B** and **C**	Lithium α
	Orange Red	39,000	**C** and **C**[1]	Red Hydrogen or Hyd. α
Brilliant Middle of Spectrum	ORANGE	40,000	α (Alpha) Band	Tube Carbon band
	Orange-yellow	41,000	Rain-band	Carbo-hydrogen Orange band
	YELLOW	43,000	**D**[1] and **D**[2]	Salt-line
	Lemon-yellow	44,000	Low Sun-band	Tube "Lucida Hydrogen"
	CITRON	46,000	(Aurora Line)	Carbo-hydrogen Citron band
	Citron-Green	48,000	**E**	Thallium α
	GREEN	49,000	**b**[1], **b**[2], &c.	Carbo-hydrogen Green giant
	Glaucous green	51,000	**c**	Tube Nitrogen band
	GLAUCOUS	53,000	**F**	Glaucous Hydrogen, or Hyd. β
Violet End	SKY-BLUE	56,000	**d**	Cæsium α
	Deep-blue	58,000	**e** and **f**	Tube Nitrogen band
	VIOLET	60,000	**G** and **g**	Violet Hydrogen, or Hyd. γ
	Lavender	63,000	**h**, **H**[1] and **H**[2]	Lavender Hydrogen, or Hyd. δ
	GRAY	67,000	Fluorescent lines	Tube Nitrogen band

The distances from centre to centre for each colour, it will be seen are by no means, regular and depend partly on the capacity of the eye to distinguish differences among colours, and partly on the intensity of the light at the place; greater intensity showing more variations within a limited range. Such however as they thus appeared to me, I have endeavoured to represent them in the FIRST and uppermost compartment of **Plate 18**; with three gradations of each colour upwards towards light, and four downwards towards dark. And some such arrangement, in its spectrum order, is probably the most practical, as well as the ultimate, reference which the world must have recourse to at last for all the kinds of colour which the list contains.

These kinds however, are only such as lie in the direct road of spectral progression from red through yellow to green, and from green through blue to violet; while in Nature at large, as witnessed daily in vegetation, minerals, chemical preparations, flames and the stars of the sky, there are endless varieties or qualities of colour to the eye, which are never seen as a whole in any one point throughout the whole length of any pure spectrum. Yet are they all derived therefrom, by mixture of some two or more of its parts, as first experimentally shown by the late Professor Clerk Maxwell; and involuntarily beheld to some extent, by every observer with one of Mr Rutherfurd's gratings of 17,296 lines to the inch, from the overlapping of the higher orders of its spectra upon each other.

Such mixtures of colours might doubtless be analyzed by spectroscopic examination into their original, spectral components, but in cases of faint illumination, the process would be tedious and sometimes uncertain. I have therefore added, for hasty eye comparisons, in the lower part of the same **Plate XVIII**, a SECOND series of nine examples of colours ready formed by mixtures more or less of *two* parts of the spectrum, say of places 36,000, and 60,000 W.N. Pl, not naturally adjacent to, or blending into, each other, naturally; and each of them exhibiting three gradations of itself upwards towards light, and as many downwards towards dark. These colours are as follows:—

NAMES OF MIXED, OR DOUBLE SPECTRUM, COLOURS.

Marroon.
Amaranth.
Crimson Lake.
Lake Red.
Rose-Pink.
Lilac.
Purple.
Blue Purple.
Ocean Blue.

Again and further on the right hand side of the lower portion of the said Colour plate or **Plate XVIII.**, I have introduced a THIRD compartment for another series of still more compound colours, or such as are formed by a mixture in various proportions of three distinct parts of the spectrum not blending into each other in any single spectrum naturally, by reason of their differences of spectrum place; they being about 36,000, 46,000, and 60,000 W.N. Place. These colours are also exhibited, each in three gradations of itself upwards towards light; and as many downwards towards dark. Their names are thus:—

NAMES OF VERY MIXED, OR TREBLE SPECTRUM, COLOURS.

Burnt Umber.
Burnt Sienna.
Brown Ochre.
Yellow Ochre.
Naples Yellow.
Raw Sienna.
Yellow Olive.
Olive.
Blue Olive.

Such lists of colours practically exhibited, have been often demanded in Observatories to compare at once with the original and self-luminous colours of stars as seen in the telescope. But if *these* lists should be so employed, I must request that they be illuminated only by white light, and that may now be accomplished. The Electric arc-light is indeed too expensive to be thought of amongst astronomers generally; Magnesium light throws out too many white smoky fumes; the best and strongest flames of oil-lamps or coal-gas burners are not white, only a beer-y brown; but Swan's and Edison's incandescent electric lamps appear to meet the case sufficiently in ordinary practice. For having recently obtained one of Swan's smallest size, fitted it into a home-made liliputian lantern, and connected it with six to eight small bichromate cells, used generally in coil excitations,—the colours of our **Plate XVIII.**, and especially its blues, seemed to come forth under its rays, with peculiar clearness and force.

GENERAL SUMMARY OF RESULTS OF MADEIRA OBSERVATION IN 1881.

If the demand be now made by the reader, to be shown in a few concluding words, what has been accomplished by this Madeiran revision of certain parts of the Solar spectrum, I would first apologise for the very short length of it which has been attempted, compared with the enormous lengths which some eminent physicists have been lately describing with much acceptance before the British Association at Southampton.

This greater length has been obtained by them, through photographing the optically dark regions beyond the furthest visible violet at one end; and at the other, both by photographing and by taking electric heat indications in the region beyond the red; or beyond where any light whatever can be seen by the glass-lens assisted human eye.

That I prefer to occupy myself with the luminous, which is the central range, and only immediately visible part of the Solar spectrum, is of course nothing to modern science, though it arise from a feeling of profoundest gratitude to the Divine Creator, who has formed both light, and that marvellous organ the eye, through which man can recognise how cheerful God-created light does make the world which he is now inhabiting. But if I have, whether rightly or wrongly, been thus confining myself confessedly to a small angular portion only of the whole of the sun's radiations, —then every one has a right to expect that I have tried to make up by increased accuracy in that small part, for what has been wanting in extent; and then the matter is about as broad as it is long, provided that such greater accuracy is still a desideratum in the parts so selected.

These two points I trust the plates, Nos. I. to XVII., will sufficiently and almost independently prove for me, through means of their chronological arrangement on every page, beginning either with Sir David Brewster or Professor Angstrom as the earliest known and generally acknowledged of latter-day authorities, and ending with my Madeira views, or in a few instances with a later authority still. The too usual process by which greater accurary is gained in modern researches amongst old walks in Astronomy, is by that most unsatisfactory process so largely illustrated just now at public expense over all the world in the matter of sun-distance—viz., by bringing out hundreds and hundreds of mutually conflicting results, one after the other oscillating backwards and forwards, just as they did twenty years ago, past a certain middle point of peculiar import. Here, on the contrary, in the parts of the Solar visible spectrum selected for examination, the crudeness and vacuities of the earlier authorities are seen in almost every case to be left, with time, infallibly behind; while most evident proofs are given that every successively later observation is certainly nearer to the truth, the refinement, and the beauty of Nature than its predecessor. So much so indeed, that we may further savingly conclude that we have not even yet touched soundings, or reached the proper limit of, or barrier to, sailing over the ocean of spectroscopic knowledge, and inquiring further into this transcendent subject of light, its nature, and operations throughout all creation.

In that case, with not a few persons of the observing order, it may be a sufficient result, for these Madeira views, and for what they have accomplished by the superiority of Mr Rutherfurd's admirable grating, over all the prisms heretofore used by myself,—that they show the importance of still further improving our instruments, and perfecting the circumstances under which they are used; certain now that such labour will be rewarded by the undoubted discovery of further, but always minuter, positive facts. And yet I trust the stage attained by the Madeira work is also able to assist us in the present day to some natural philosophy results of important bearing in both cosmical astronomy and terrestrial physics.

In Solar spectroscoping generally, there are three main points to be aimed at: 1st, to ascertain the existence, appearance, and place of any particular and so-called "Fraunhofer," or black lines therein; 2d, to find out what special chemical element any particular line, or slit-reproduction in that recorded place, represents; and 3d, to decide the locality, in all the long line between the instrument and the sun, where such substance imparts its peculiar property to the light passing through it.

The first of these points is taken up already by the drawings, and what we have said of them, at so much length in the Notes from p. 5 to p. 23; while some desirable light is also shed by them on the second and third points, perhaps rather unexpectedly.

I have already spoken, in that department of "Notes on the Plates," of the lamentable ignorance we are all in touching what chemical element makes great **A**, great **B**, and the Alpha band, the chief existences of the whole visible spectrum; and that this is a true representation of the case may be gathered from the late meeting of the British Association at Southampton (1882); where, while the President of the chemical section spoke of great **B** as being produced by watery vapour in the earth's atmosphere, or pronounced it to be a telluric line (see "Nature" for Aug. 24, 1882, p. 405, col. 1), another eminent scientist in the physical section is reported (in "Nature" for Oct. 12, p. 585, col. 2) to have said, "the **B** and **A** lines could not be claimed as telluric lines, much less as due to aqueous vapour, but must originate between the sun and our atmosphere."

The latter author (Captain W. de W. Abney, R.E.) is also stated to have then "confirmed the presence of benzene and ethyl in the same region. He had found their presence indicated in the spectrum at the sea-level, and found their absorption lines with undiminished intensity at 8500 feet. Thus, without much doubt, hydrocarbons must exist between our atmosphere and the sun, and it may be in space."

Now the usual method of decision whether a spectral line of unknown chemical origin * be solar or telluric, is by noting whether it remains stationary in character as the sun descends from the zenith to the horizon, or increases rapidly in intensity. To this general test the Madeira observations

* If its chemical origin be known, the temperature at which the substance can only exist as a permanent gas, must have a powerful voice in its location.

add for Solar lines of the hottest kind, as with those of hydrogen, magnesium, and sodium, a broadening and paleness of their lines accompanied with outside haze, produced by the explosions and various velocities of the incandescent gases of those metals, or metalloids, in various parts of the sun's photosphere at the same instant of time.

When these symptoms are observed, after clearing away all the sources of haze arising from imperfect optical instruments, there can be no doubt about the intense Solar locality of the phenomenon; and a very definite point is thereby gained for physical theory, because such characteristics are never seen on or about the only telluric lines we can be *quite* certain about, viz., water-vapour lines. As seen darkly in the faint spectrum-light of a mere cloudy atmosphere, they do indeed show sufficiently hazy bands, the "rain-bands" of the meteorologists; but on the sun, they resolve themselves into lines as sharp, precise, and black as anything that can well be imagined; —see the Madeira views of "little **a**," and the intrusive accompaniments to great **C** and great **D** on a low sun.

We can speak so extra-positively of water-vapour lines, because we know that water-vapour is in our atmosphere, close round about us, and can measure its varying amount from time to time by both chemical and physical methods. But the Alpha band we may be almost as certain about, for though we do not know what causes it (and mainly because the great societies in London, rich in their own funds, and still more in their dotations by the central government, will not experiment in the only likely way of succeeding, viz., by cold transmission)—yet I presume no one denies the Alpha to be a truly telluric band of something or other, seeing that it nearly, or entirely with ordinary instruments, vanishes in the thinner coats of the earth's atmosphere near the zenith of any place; but grows portentously broad and black as the sun descends towards the horizon. And now, in addition to that testimony, the Madeira views, with the fine definition under the highest dispersion imparted to them by the admirable Rutherfurd grating, show the Alpha band to be always composed of lines, of the thinnest, blackest, best defined order: demonstrating at once that the gas which produces those reversals of the sun's light must be situated in our earth's cool surroundings, so as never to be subjected to the same turmoil of heat influences which everything, in close proximity to the sun itself, must ever be.

But great **A** is another variety again of spectral existence; for, with lines as well defined and black as those of the Alpha band at its best, it yet keeps up such a grand visibility at altitudes approaching the zenith, that I was led so far back as 1877, when in Portugal, to start the idea of its being, not as then usually held a telluric line,* but rather a Solar one of some external kind. This idea, too, is eminently confirmed by the Madeira observations, though without necessarily conflicting with Captain Abney's suggestion, that it may really depend on the gases occupying the 92 millions of miles of space between the outermost acknowledged denser atmospheres of both earth and sun.

A few years ago that space would have been looked on as void of everything capable of acting as a gas in spectroscopy; but when every meteorite that is analysed is found densely packed with occluded hydrogen, and every 9 in 10 comets are seen to shine with carbo-hydrogen light, and from

* That great authority Prof. Angstrom pronounced "great **A**" to be telluric, because to his observation "it reinforced itself towards sunset." *That* it no doubt appeared to do; but partly from causes of a different kind, not corrected for by him.

time to time break up and scatter their contents; and when Dr Siemens' so generally accepted theory of the re-generation of the sun's light and heat depends on gases which, after combining in heat on the sun's surface, stream out into all wide space to become dissociated there while in their utmost tenuity, and then serve over again on returning to the sun by a different course,—we are compelled to prepare for possible proofs, in the advancing instrumentation of our times, for many various elements which the mighty storehouses of space may contain.

But in that case we must be further prepared to find some very similar gases to those at high temperature in the sun's, existing at medium, rather than the very lowest, temperature in the earth's, atmosphere; and these Madeira observations, while not denying an outside Solar, and even a partly space, origin to great **B**, very similarly to great **A**,—do yet claim for **B** (whatever may be the gas producing it) a very notable amount of increase of intensity in its lines in a low, over a high, sun; or declare for its being in part of telluric origination also.

Indeed in Portugal, in 1877, working with prisms only, far less in their united power to the one grand Rutherfurd Diffraction Grating, which I had the privilege of using in Madeira, I could see so very little of great **B** at high altitudes, that I recorded it as *telluric* on the same page where I had entered that great **A** might be a *solar group* of some kind. But I may have been partly misled with regard to **B**, both by the then weakness of the apparatus employed, and the circumstance that effects, very like telluric strengthenings of lines towards sunset, do take place in the red, but adventitiously only, dependent chiefly on the brighter and more refrangible part of the Solar light being then cut off or absorbed by the increased thickness of the atmosphere—effects which must be watched and guarded against more narrowly in the future than they have been in the past.

All that we can, in this category, be absolutely certain about at present, is the physical feature; first, I believe, developed in these Madeira Spectrum Drawings, that none of these latter disputed lines have any of those abundantly perceivable distraction features of **C**, **F**, and "near **G**," which tell so plainly that those lines are in the midst of the hottest influences, fiercest explosions, and most violent disturbances of the fluid or gaseous but always fiery Solar surface itself. But why some of Iron's lines present very similar appearances, and others, in spectral place close to them, do not, can only at present be relegated to further and more powerful efforts of observation.

APPENDIX.

Containing a Letter from Professor JOSIAH P. COOKE, Cambridge, Mass., U.S., Oct. 8, 1882, and a reprint of his Paper in the Proceedings of the American Academy (Boston) of date January 1866,—referred to by him.

[*Copy.*]

"My dear Sir,—I thank you for the interesting book on 'Madeira Meteorologic,' which, in consequence of a long absence from home, I have only just received. Your observations on the spectrum lines caused by aqueous vapour interested me, especially as I once did sufficient work on that subject myself to be able to appreciate how marked the effect of *selective* absorption is throughout the less refrangible portion of the spectrum.

"The atmospheric conditions here, during this warm (humid but bright) autumn weather, are not unlike those you noticed (as characterising Madeira); and the difference between the effect of true vapour in its aeriform state (perfectly transparent) and mist (more or less opaque however attenuated) has seldom been made out.

"If you are inclined to look up my old work on this subject, you will find it in the Proceedings of the American Academy of Boston, Vol. vii., page 57. I wish I had an extra copy to send.—With renewed thanks, believe me, etc.

"(Signed) JOSIAH P. COOKE.

"To C. PIAZZI SMYTH, Esq."

The particular Academy publication alluded to by Professor Cooke does not come to the Royal Observatory, Edinburgh,—though that very small institution is most richly donated, in books large and small, by an immense, and constantly increasing, number of publishing Societies, Observatories, and scientific individuals throughout the whole of the United States of North America; for which liberality we cannot be too thankful.

But having applied at the Royal Society, Edinburgh, I have obtained a loan of the volume named, and have found the paper in question so admirable, so decided in its priority, and so little read here as yet (for it was uncut)—that I trust I shall only be showing proper respect for good and early work in spectroscopy, and shall not be displeasing the eminent author of such extensive European, as well as American, fame, if I now, at the very point of closing my book for publication, request the publishers to reproduce Professor Cooke's ancient paper *verbatim;* and here accordingly it is.

C. P. S.

ON THE AQUEOUS LINES OF THE SOLAR SPECTRUM.

By JOSIAH P. COOKE, Jr. (1866.)

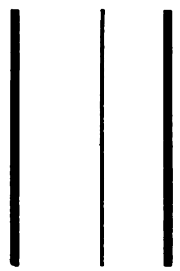
A careful examination of the solar spectrum, continued during several months with the spectroscope described in a recent article of the American Journal of Science,* has led me to the conclusion that a very large number of the more faint lines of the solar spectrum, hitherto known simply as *air* lines, are due solely to the *aqueous vapour* of our air, and hence that the absorption of the luminous solar rays by the atmosphere is at least chiefly owing to the aqueous vapour which it contains.

The appearance of the Fraunhofer's line D, seen under precisely the same conditions, but with increasing quantities of aqueous vapour in the atmosphere, is shown in figures 1, 2, 3, and 4. The D line is selected, because, being a favourite test object for the spectroscope, its general appearance is well known to all observers. But even more marked changes than those here illustrated have been noticed in other, although chiefly in contiguous, portions of the solar spectrum.

January 5th, 1866.

Temperature 10° F.
Dew-point 1·6° F.

FIG. 1.

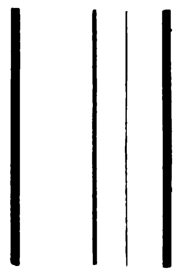


Weight of vapour in 1 cubic foot of air . . } 0·81 grs.

December 25th, 1865.

Temperature 46° F.
Dew-point 33·4° F.

FIG. 2.

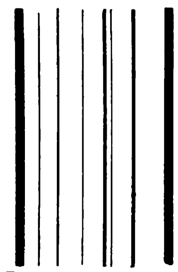


Weight of vapour in 1 cubic foot of air . . } 2·42 grs.

December 26th, 1865.

Temperature 55° F.
Dew-point 46·5° F.

FIG. 3.

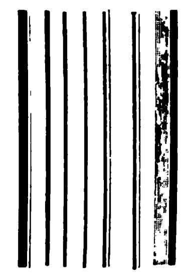


Weight of vapour in 1 cubic foot of air . . } 3·76 grs.

November 17th, 1865.

Temperature 70° F.
Dew-point 64·0° F.

FIG. 4.



Weight of vapour in 1 cubic foot of air . . } 6·57 grs.

These changes attracted my attention from my earliest observations with the spectroscope; but with my first instrument, and the bisulphide of carbon prisms then employed, it was almost impossible to eliminate the effects which might be caused by the variations in the condition of the instrument itself; and as these were known to be very great, it was possible that they might account for all the variations observed. With the improved instrument, however, just referred to, absolute constancy of action is obtained, and all merely instrumental variations avoided.

A peculiar condition of the atmosphere gave the first clue as to the cause of the changes under consideration. The weather on the 17th of November 1865, at Cambridge, Massachusetts, was very unusual even for that peculiar season known in New England as the Indian Summer. At noon the temperature on the east side of my laboratory was 70° F., while the wet-bulb thermometer indicated 66°, showing an amount of moisture in the atmosphere equal to 6·57 grains per cubic foot. At the same time the atmosphere was beautifully clear, and the sun shone with its full splendour. I have never seen the aqueous lines of the spectrum more strongly defined than they were on this day; and the total number of lines visible in the yellow portion of the spectrum was at least ten times as great as are ordinarily seen. The appearance of the D line on that day is shown in fig. 4. Between the two familiar broad lines D_1 and D_2 there were eight sharply defined lines of unequal intensity, which is only very imperfectly represented by the woodcut. In addition to these, on the more refrangible side of the space between the two D lines, there was a faint but broad nebulous band, barely resolvable into lines of still smaller magnitude.† It is impossible to represent this band accurately with a woodcut; and the shaded broad band marked κ on the right-hand side of fig. 4 only serves to indicate its position and approximate breadth.

The 26th of December was also a warm day for the season, with a brilliant sun. At one o'clock P.M. the dry-bulb thermometer marked 55°, the wet-bulb 50°, and hence the amount of moisture in the atmosphere was 3·76 grains per cubic foot. The appearance of the D line at this time is shown in fig. 3. Two of the lines, η and θ, and the nebulous band κ, seen on the 17th of November, were invisible, and moreover the group of three lines δ ϵ ζ on the left-hand side of the figure were only just within the limits of visibility.

* American Journal of Science and Arts, vol. xi., November 1865.

† We use this word in the same sense in which it is used by astronomers with reference to the fixed stars.

On the 25th of December only two lines were visible within the D line, marked α and β, in fig. 2, and the last of these was quite faint. The temperature at the time of observation was 46°; the wet-bulb thermometer indicated 40°, and the amount of moisture in the air was 2·42 grains per cubic foot. The sky was clear and the sun brilliant. Lastly, on January 5th, 1866, one of the clear cold days which are so common in our climate during the winter, only the single line α was visible within the D line, as is shown in fig. 1. At the time of observation, near noon, the dry-bulb thermometer marked 10°, the wet-bulb 9°, and hence the amount of moisture in the atmosphere was only 0·81 of a grain per cubic foot. The sun, however, was as brilliant as in either of the previous cases. The D line also appeared as in fig. 1 on the 8th of January 1866, when the thermometer at noon stood at 10° below zero Farenheit, and when the barometer attained the unexampled height of 31 inches.

The above figures have been drawn so as to show, as nearly as possible, the relative intensity of the different lines under different atmospheric conditions. As no accurate means of making the comparison are yet known, I was obliged to depend upon my eye alone, and small differences at different times of observation may easily have escaped my notice. Indeed, I should have been liable to great error, were it not for the fact that one of the lines within the D line, marked α in all the figures, does not vary in intensity, and served as a constant standard in making the observations. This is the only line which is given by Kirchoff in his chart of the solar spectrum between the two D lines, and it is referred by him to the Nickel vapour,—as the D lines themselves are to the Sodium vapour, in the sun's atmosphere. It is an undoubted solar line, and has been drawn with the same strength in all the figures in order to show that it is invariable.

With a very dry atmosphere the line α is the only one which appears within the D lines, as shown in fig. 1. With a slightly greater amount of vapour the line β makes its appearance. As the amount of vapour continues to increase, this line becomes more and more prominent, until at last, as shown in fig. 4, it is even more intense than the line α. A careful comparison of these two lines might indeed serve as an approximate measure of the amount of vapour in the atmosphere; and a series of comparisons made under the same conditions at different heights would give data for determining the law according to which the amount of vapour decreases with the elevation above the sea-level.

All the aqueous lines change in intensity like the line β. They are first seen very faintly when the amount of vapour in the air reaches a definite point, varying for the different lines, and gradually gain in intensity as the amount of vapour increases. Thus the group of three lines δ ϵ ζ do not appear in fig. 2, are barely visible in fig. 3, but become very marked in fig. 4.* The lines η and θ and the nebulous band κ do not appear until the air is very moist; and even when it contains 6·57 grains of vapour per cubic foot, they are still very faint. Under yet more unusual atmospheric conditions they will undoubtedly become more intense, and we shall then probably be able to completely resolve the nebulous band and count the lines of which it consists.

It is hardly necessary to repeat, that the examples here given are selected from a large number of observations. During the cold dry weather of winter the appearance of the D line is uniformly as shown in fig. 1, the line β only occasionally appearing when the atmosphere becomes more moist. During the warm weather of summer, when the absolute amount of moisture in the air is in almost all cases greater than in winter, the appearance of the D line is as uniformly that shown in fig. 3. It is only very rarely in the dry climate of New England, even during the summer, that all the lines shown in fig. 4 are visible; and, as already stated, I never before saw them so sharply defined as on the 17th of November last.

Several conditions must evidently concur in order that the aqueous lines should be developed in their greatest intensity. In the first place, the air must be charged with vapour not only near the surface of the earth, but also through a great height of the atmosphere. Local causes might greatly increase the amount of moisture in the lower strata of the atmosphere, and affect powerfully the hygrometer, which would not, to the same extent at least, influence the indications of the spectroscope. In the second place, other things being equal, the intensity of the aqueous lines must be strengthened by increasing the length of the path of the sun's rays through the atmosphere, and this is the longer the lower the altitude of the sun. But then, again, the intensity of the light has such an important influence on the definition of the lines, and the slightest haze in the atmosphere so greatly impairs their distinctness, that I have generally found that the aqueous lines are seen best when the sun is near the meridian. Hence, with an equal amount of moisture in the atmosphere, the late autumn may be a more favourable season for seeing the aqueous lines than the summer; for then not only must the solar rays, when most brilliant at noon, traverse a greater extent of air, but, moreover, the atmosphere at this time is usually clearer, and the reflected beam of light which enters the spectroscope is at times more brilliant than when the sun attains a higher elevation and the light is reflected under less favourable conditions.

In the examples cited above, the comparisons were made under as nearly as possible the same conditions, so as to eliminate all causes of variation except the one under consideration. Days were selected when the atmosphere was perfectly clear, and the sun's light, so far as I could judge, equally brilliant. Moreover, the position of the spectroscope and mirror remained unchanged during the whole time. This mirror, which is used for reflecting the sun's light upon the slit of the spectroscope, is so arranged that it can be turned into any position by the observer while his eye is at the eye-piece of the spectroscope, and it was always carefully adjusted at each observation to the position of best definition. The manipulation of the mirror is fully as important in the use of the spectroscope as it is in microscopy.

* With an increasing quantity of vapour in the atmosphere the line γ of fig. 3 is seen before the group of lines δ ϵ ζ, and an intermediate figure between 2 and 3 might be given showing only the lines D_1 α γ β D_2.

It will be of course understood that the power of developing these faint aqueous lines depends very greatly on the optical capabilities of the spectroscope, and that the figures here given are relative to the instrument used in the observations. This instrument has been fully described in the article already cited. It is sufficient for the present purpose to state that it is provided with nine flint-glass prisms * of 45° refracting angle, which bend the rays of light corresponding to the D line through an angle of 267° 37′ 50″, and that corresponding to the H_1 line through an angle of 280° 42′ 20″, when each passes through the prisms at the angle of minimum deviation. The dispersive power of the instrument for these two rays is therefore equal to 13° 4′ 30″, and the rays corresponding to the two D lines are separated 1′ 10″. The object-glasses of the two telescopes of this spectroscope are 2¼ inches in diameter, and have a focal length of 15½ inches, and lastly the size of the prisms, and of the various parts of the instrument, is adapted to these dimensions. With a more powerful instrument a larger number of aqueous lines would be seen under the same atmospheric conditions. The Cambridge instrument has a set of sulphide of carbon prisms which disperse the light nearly twice as much as the flint prisms. The sulphide of carbon prisms are very variable in their action; but, under the best conditions, they might show the D line as in fig. 3, when with the flint prisms it would appear as in fig. 2.

The facts stated in this paper fully account for the discrepancies in the representations which different observers have given of the D line. Some time since, Mr. Gassiot, of London, gave in the *Chemical News* a representation of the D line as seen with his instrument, showing several lines in addition to those seen by myself and other observers. On visiting the Kew Observatory, in the summer of 1864, I was surprised to find that this instrument was less powerful than the one I was then using; and I also learned that these lines were only seen on a single occasion. The moist climate of England is the evident explanation of the additional lines.

As I stated at the first of this paper, the D line has been selected simply to illustrate a general truth. The development of aqueous lines in contiguous portions of the spectrum is even more marked than in the exceedingly limited portion here represented. Indeed, as has been already intimated, the number of these lines seen in the yellow region of the spectrum, on the 17th of November, was at least ten times as great as that of the true solar lines. That part of the yellow of the spectrum which lies on the more refrangible side of the D line, and in which during dry weather only a comparatively few lines can be distinguished, was then as thickly crowded with lines as the blue or the violet, but the lines were of course far less intense.

Professor Tyndal, of London, has shown by a remarkable series of experiments with the thermo-multiplier, not only that aqueous vapour powerfully absorbs the obscure thermal rays, but also that the elementary gases of the atmosphere exert little or no action upon them. I have endeavoured to establish in this paper, from direct observations with the spectroscope, a similar truth in regard to the luminous rays. It has been estimated by Pouillet and others that about one-third of the solar rays intercepted by the earth are absorbed in passing through the atmosphere; and it now appears that aqueous vapour is a most important, if not the chief, agent in producing this result. It is impossible, however, from any data we yet possess, to determine how great a power of absorption is exerted by the oxygen and nitrogen gases which constitute the great mass of our atmosphere. I have shown that a very great many, and I have no doubt that almost all the lines hitherto distinguished as air lines are simply aqueous lines; but it is very difficult to distinguish atmospheric lines from the true solar lines, and our knowledge of the first is as yet very incomplete. It still remains to make careful comparisons throughout the whole extent of the spectrum, before we can absolutely determine the relative absorbing power of the different constituents of our atmosphere.

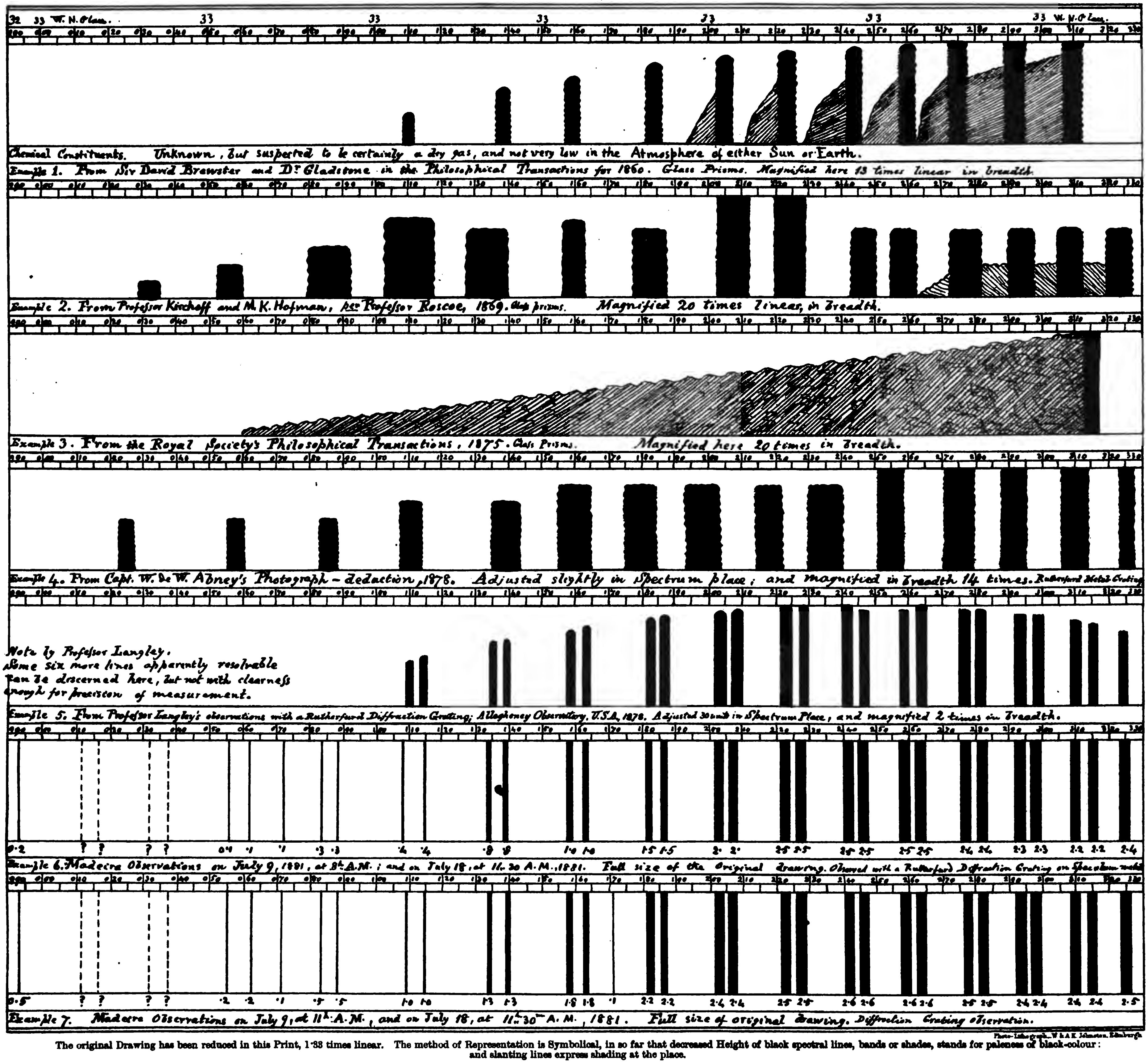
One other inference from the facts here developed is worthy of notice before closing this paper. It has been for some time suspected that the blue colour of the sky was in some way connected with the vapour in the atmosphere; and it is a fact of common observation that this colour is more intense during the moist weather of summer than during the more dry weather of winter. The distribution of the aqueous lines through the solar spectrum not only confirms the opinion previously entertained, but also points to the cause of the colour. So far as my observations have extended, the aqueous lines are almost wholly, if not completely, confined to the less refrangible portion of the spectrum. Here they are found in vast numbers, and I am not positive that they exist anywhere else. If, then, the aqueous vapour absorbs most powerfully the yellow and red rays of the spectrum, the blue colour of the sky is the necessary result. The colour is therefore due to simple absorption, and not to repeated reflections from the surface of drops of water, as some physicists have supposed.

As can readily be seen, the aqueous lines of the solar spectrum present a very wide field for investigation, but one which can only be cultivated under peculiar atmospheric conditions. This paper is only intended to open the subject. I hope to be able to continue the study on every favourable opportunity, and shall take pleasure in communicating any future results to this Academy.

* These prisms were furnished by the American Academy from the income of the Rumford Fund, appropriated for investigations on light and heat. See Proceedings of the American Academy, Annual Meeting, May 24th, 1864.

SUBJECT 1.—OF GREAT A, ITS PRELIMINARY BAND ONLY, IN HIGH, AND MODERATELY HIGH, SUN. THE SPECTRUM COLOUR THEREABOUTS A DEEP RED.

PLATE I



The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

Subject 2.—Great A, its own Colossal Line, or Band of Lines, in High, and moderately high, Sun. the spectrum colour a Deep Red.

PLATE II

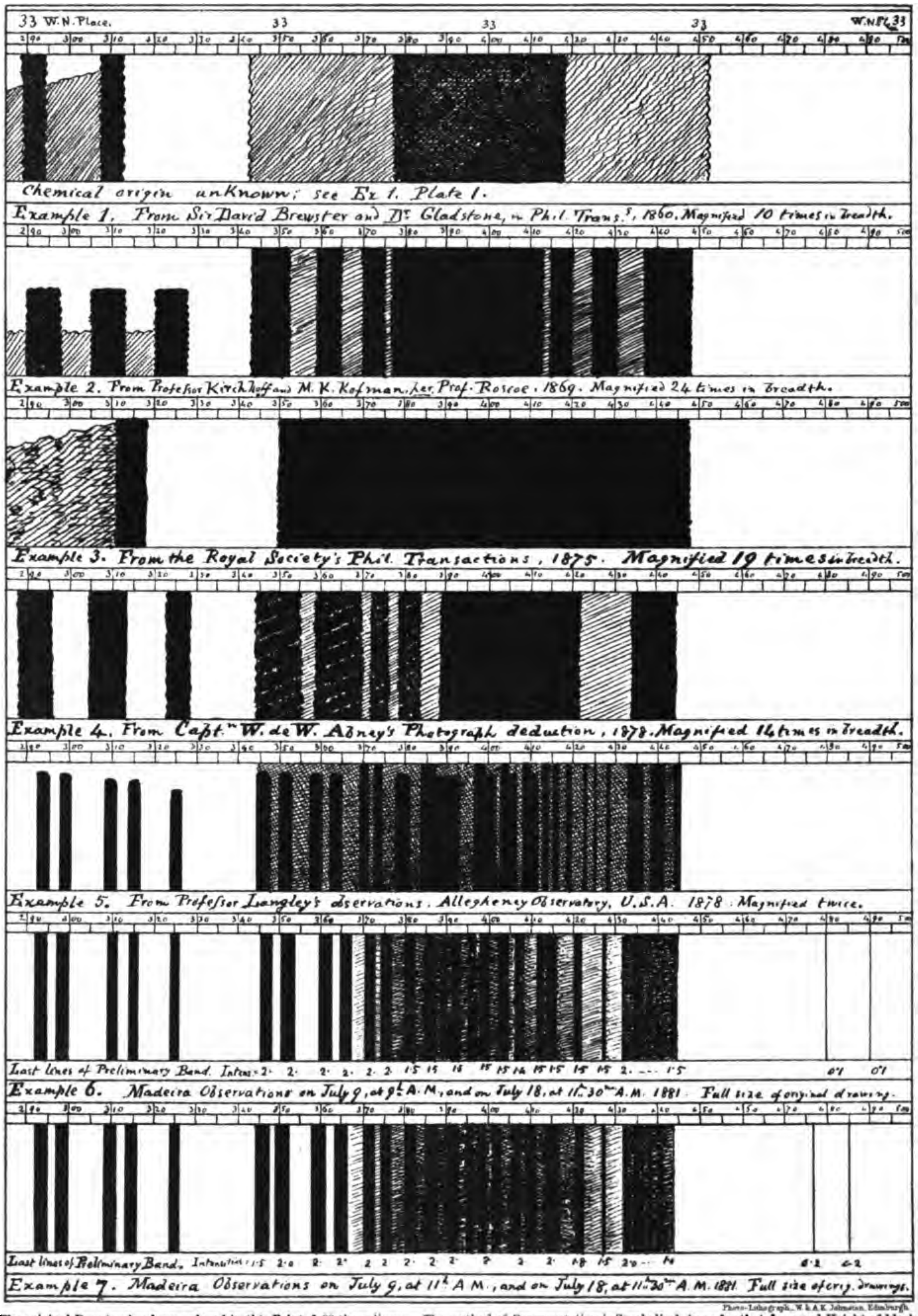


Photo-Lithograph, W. & A. K. Johnston, Edinburgh.

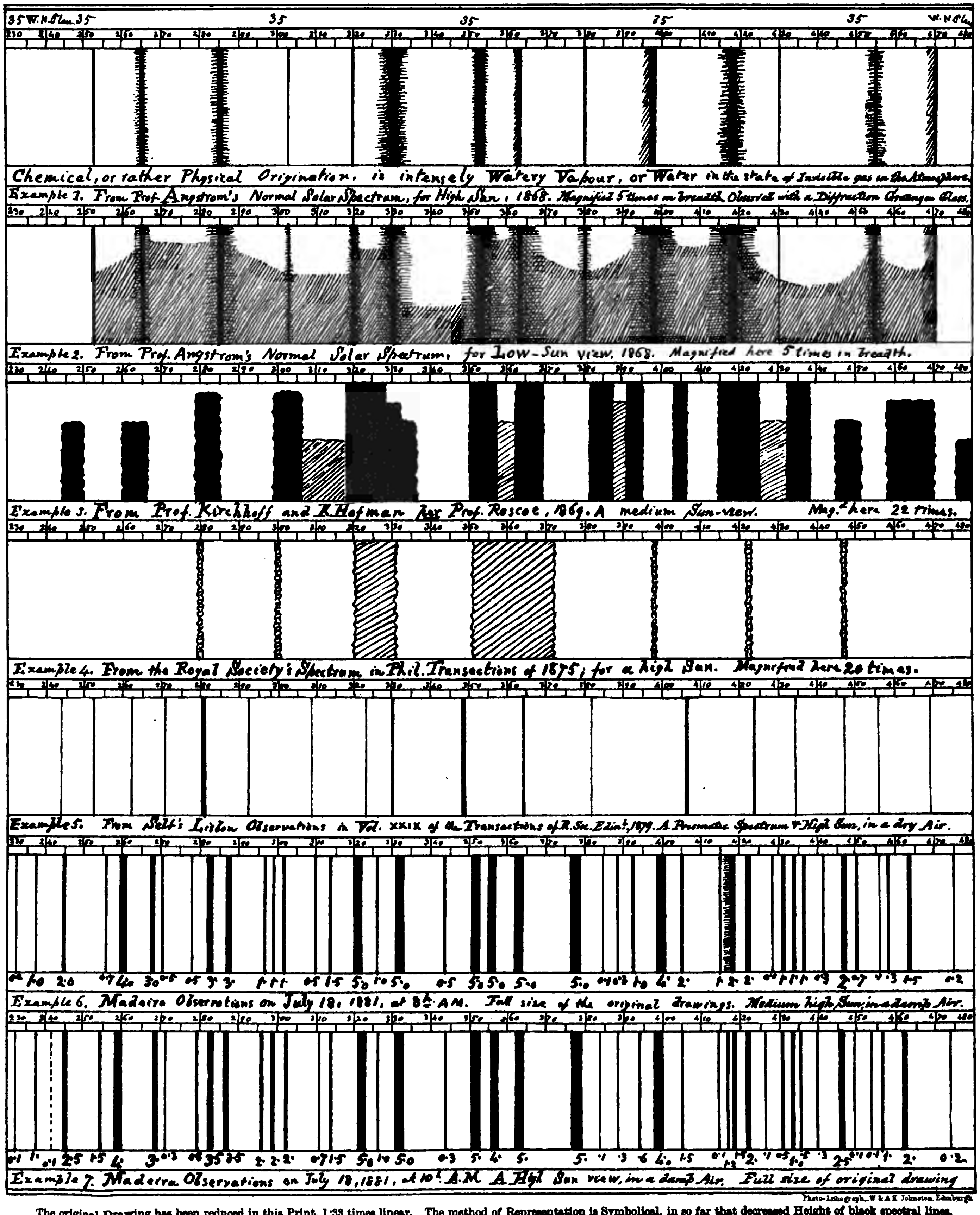
The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

SUBJECT 3.—"LITTLE a," ITS BAND OF LINES,

IN HIGH, AND MEDIUM HIGH, SUN AT MADEIRA, IN HIGH, AND LOW, SUN ELSEWHERE.

THE SPECTRUM COLOUR, A PURE RED.

PLATE III



The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place

SUBJECT 4.—GREAT B, ITS PRELIMINARY BAND,

AS SEEN IN A HIGH SUN.

THE SPECTRUM COLOUR, PURE AND PERFECT RED.

PLATE IV

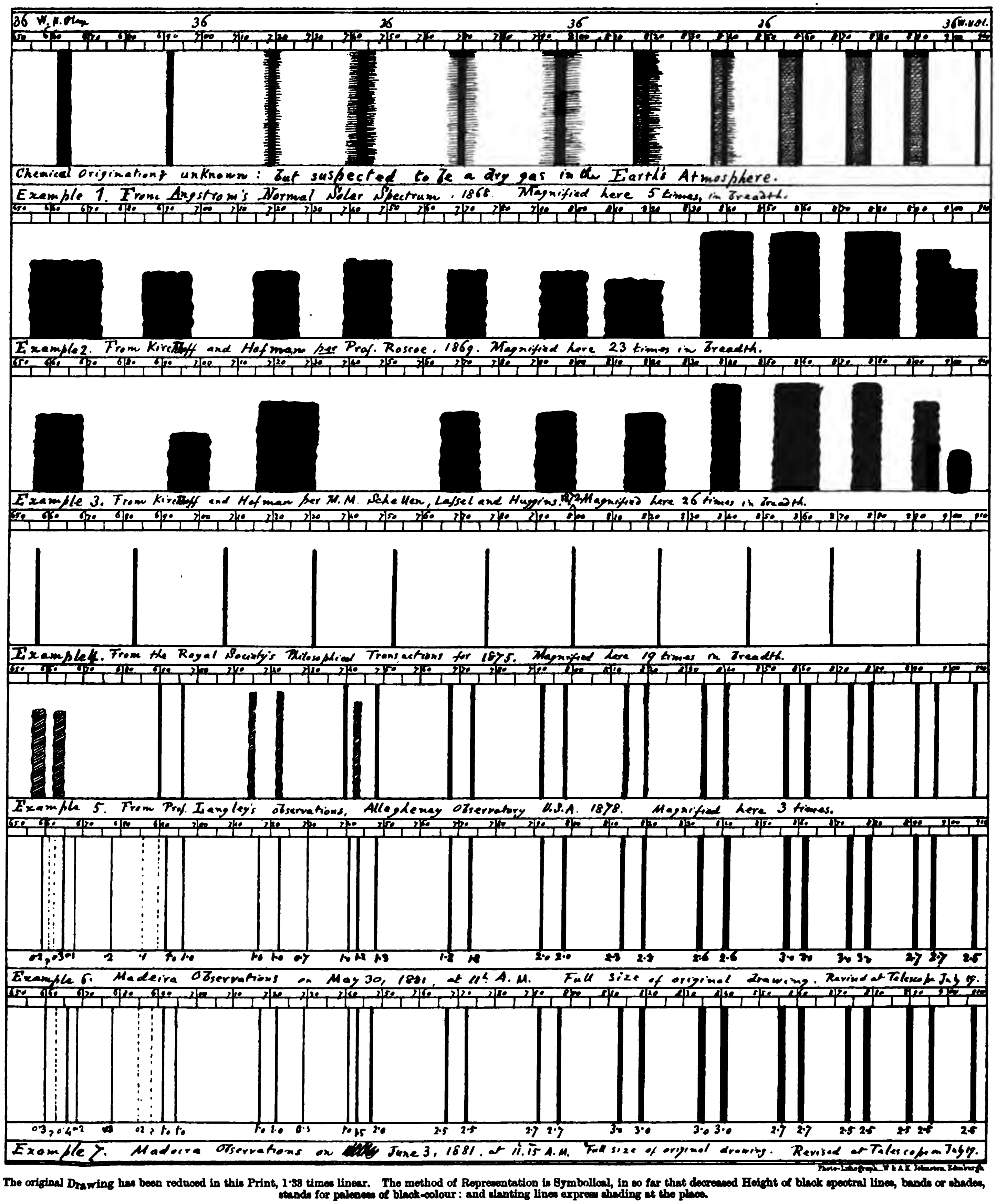


Photo-Lithograph, W & A K Johnston, Edinburgh.

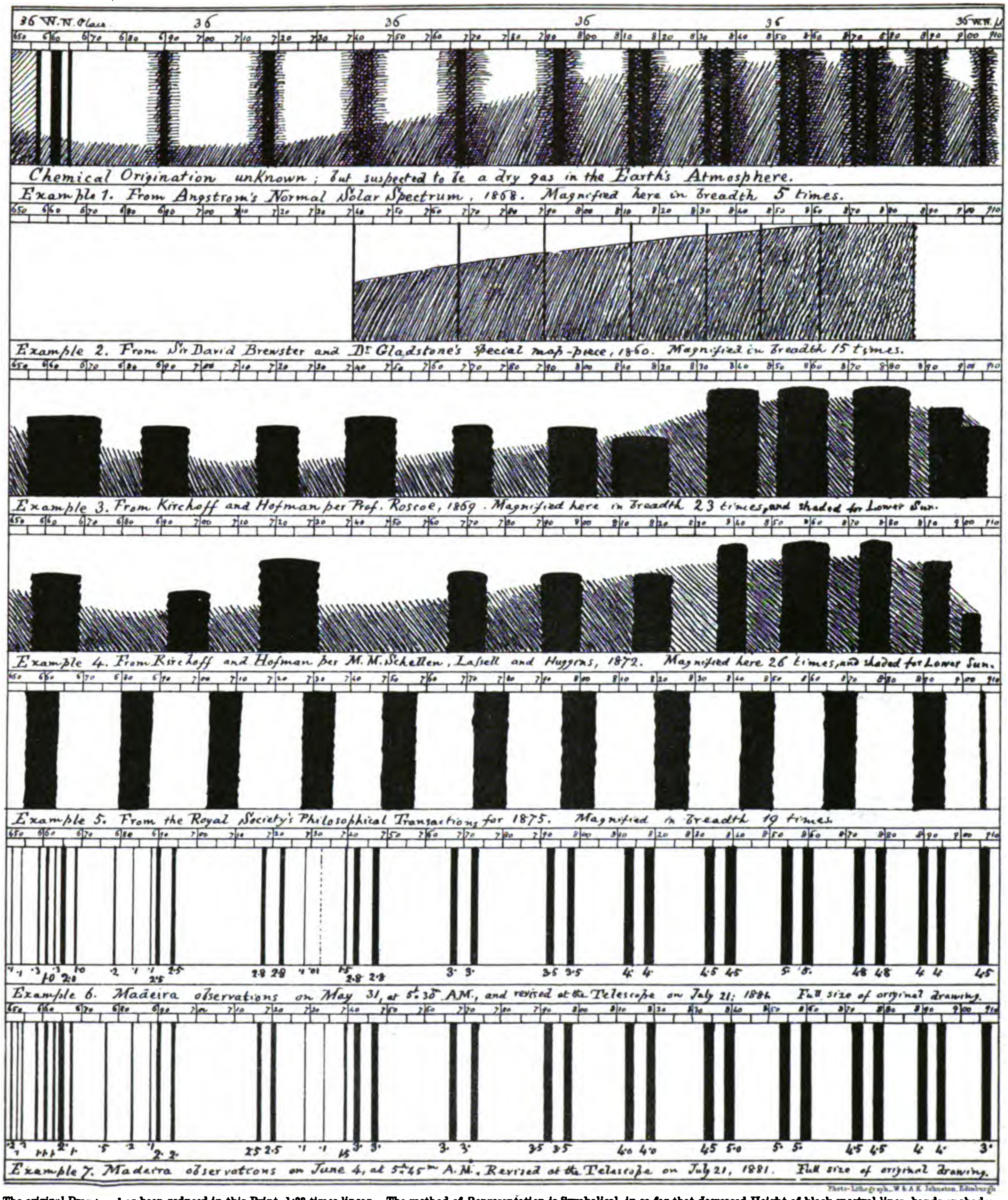
The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

Subject 5.—Great B, its preliminary Band,

in a Low Sun.

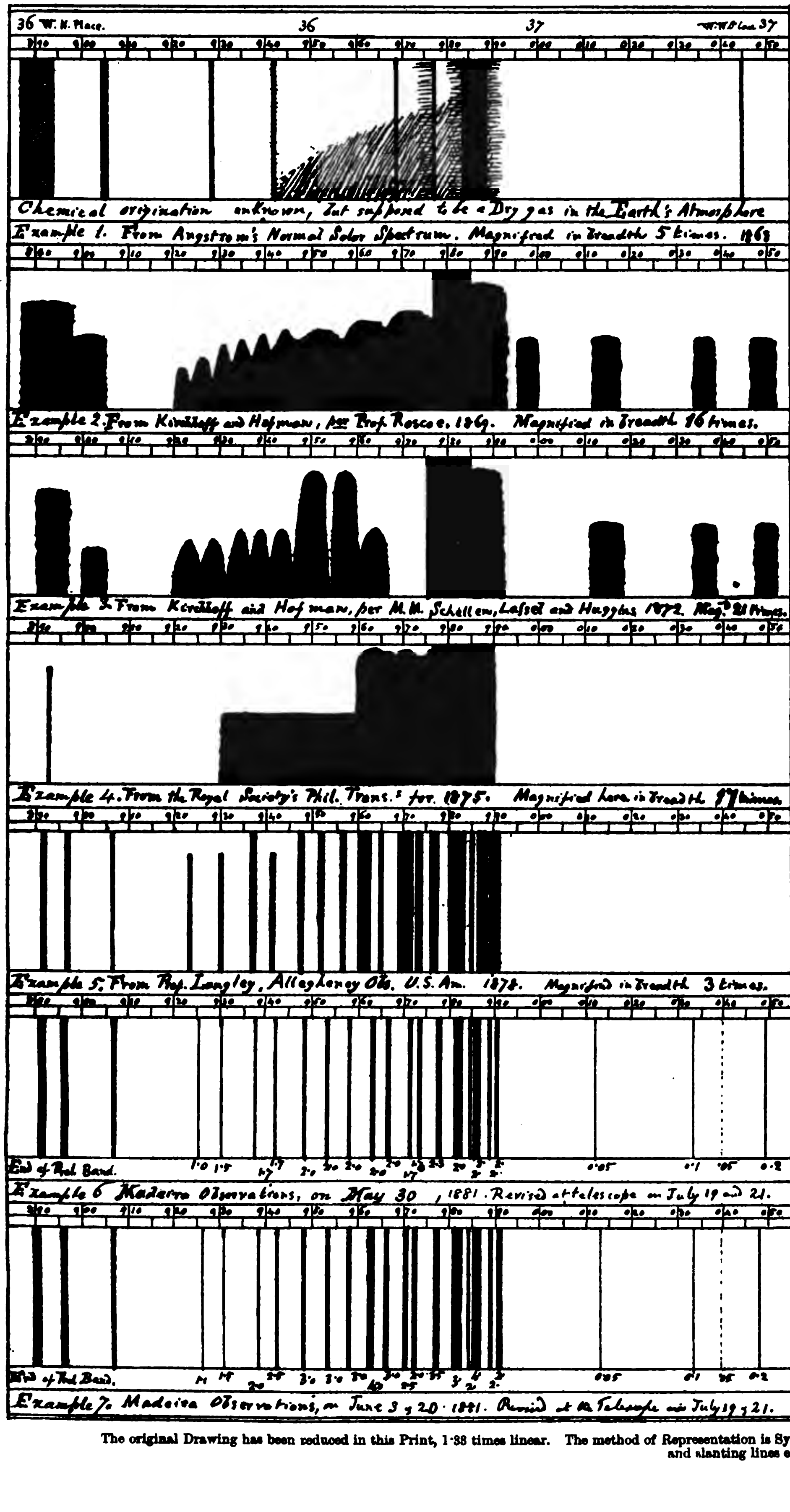
the spectrum colour, a Pure and Perfect Red.

PLATE V



The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

Subject 6.—Great B, and its Attached Band, in a High, or Noon-tide Sun. The Spectrum Colour, a Pure and Perfect RED.



Subject 7.—Great B, and its Attached Band, in a Low, or Six-hour Sun. The Spectrum Colour, a Pure and Perfect RED.

PLATE VI

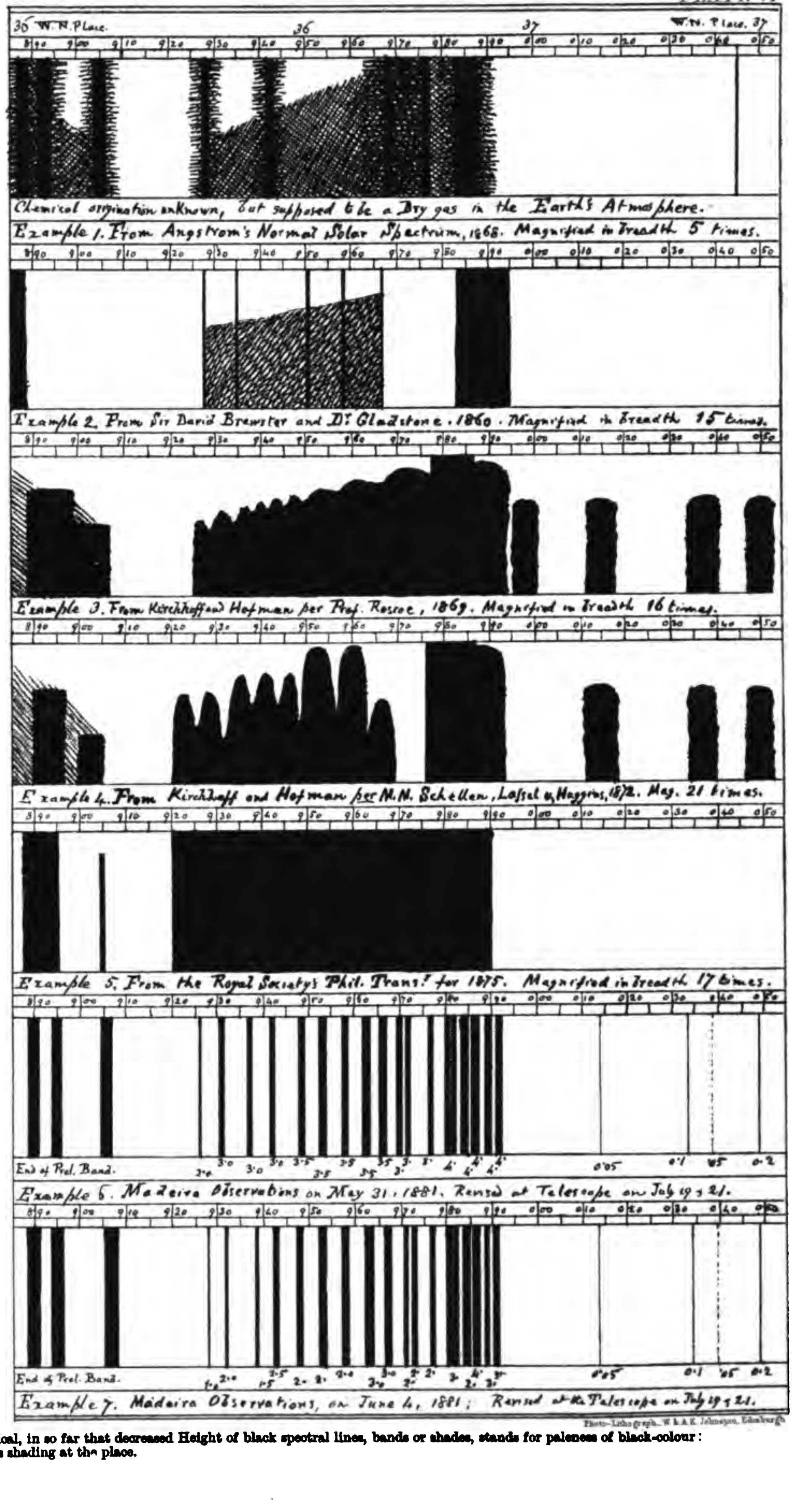


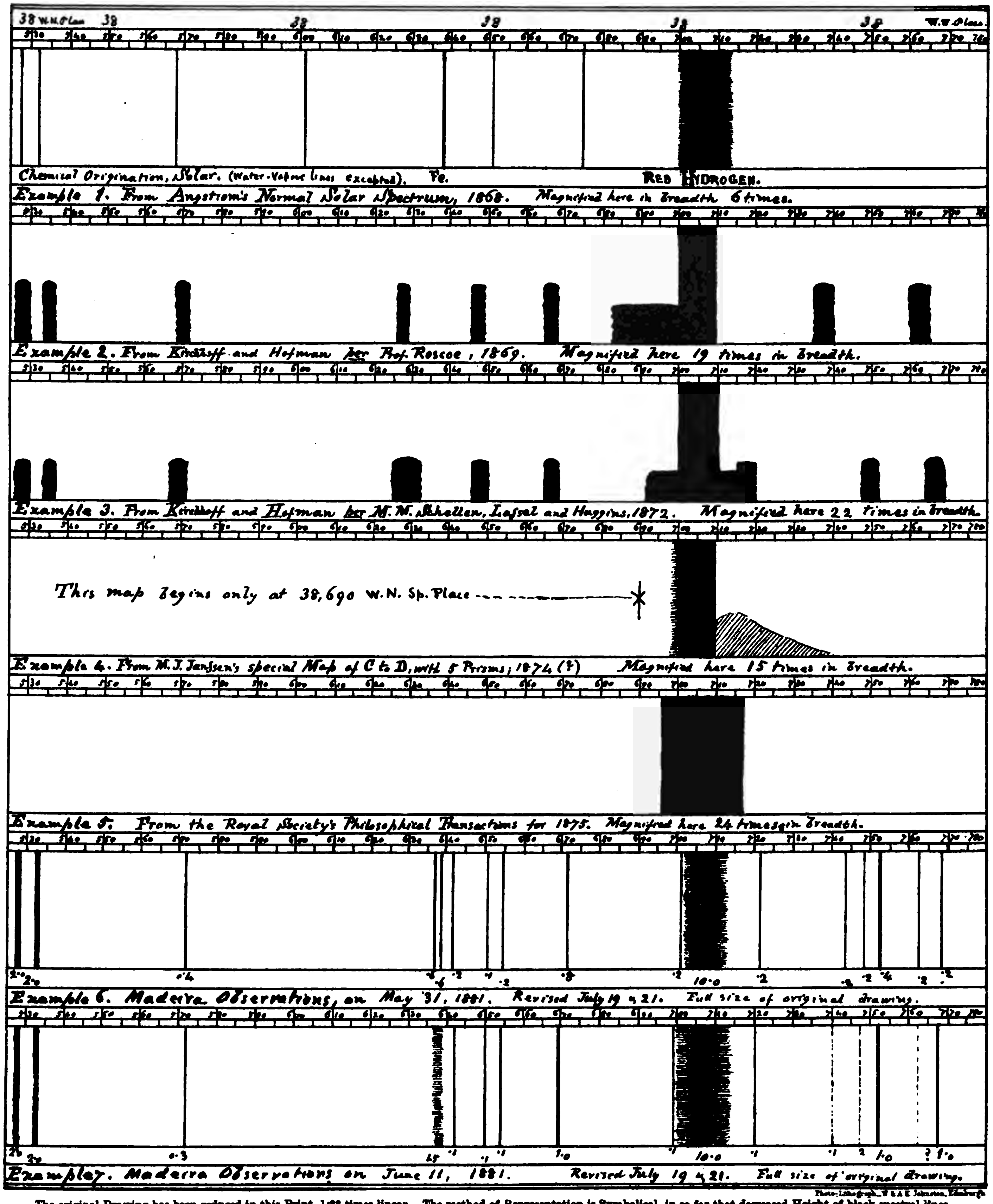
Photo-Lithograph. W. & A. K. Johnston, Edinburgh

The original Drawing has been reduced in this Print, 1·38 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

Subject 8.—The Great C line in High Sun.

The spectrum colour of the place, a Scarlet Red.

PLATE VII



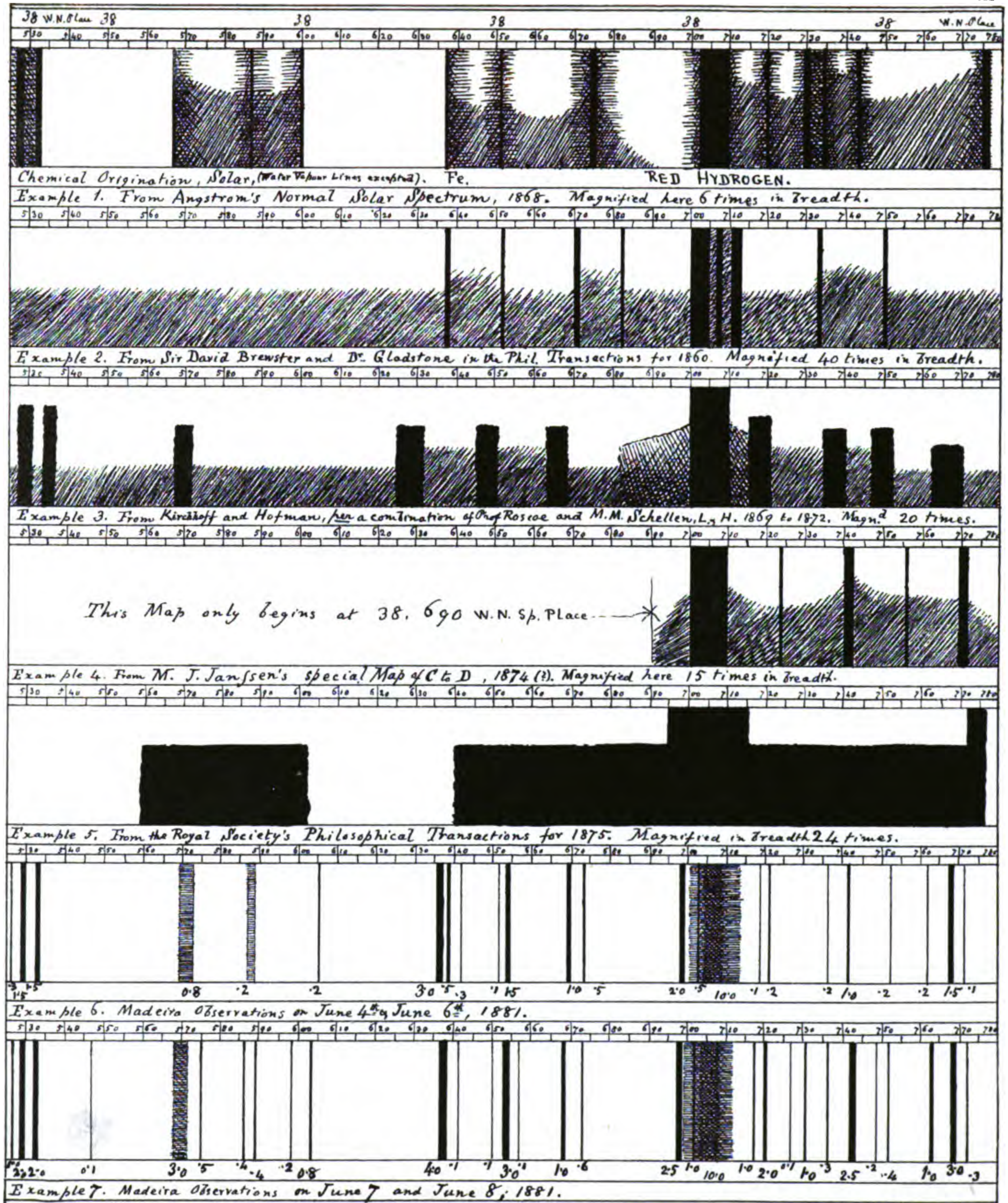
The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

Subject 9.—The Great C line,

in a Low, or Six-hour, Sun.

The spectrum colour of the place, a Scarlet Red.

PLATE VIII



The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

SUBJECT 10.—THE α (ALPHA) BAND (CALLED ALSO "C⁶," BY SIR DAVID BREWSTER), IN A HIGH SUN.

THE SPECTRUM COLOUR OF THE PLACE, A FULL ORANGE.

PLATE IX

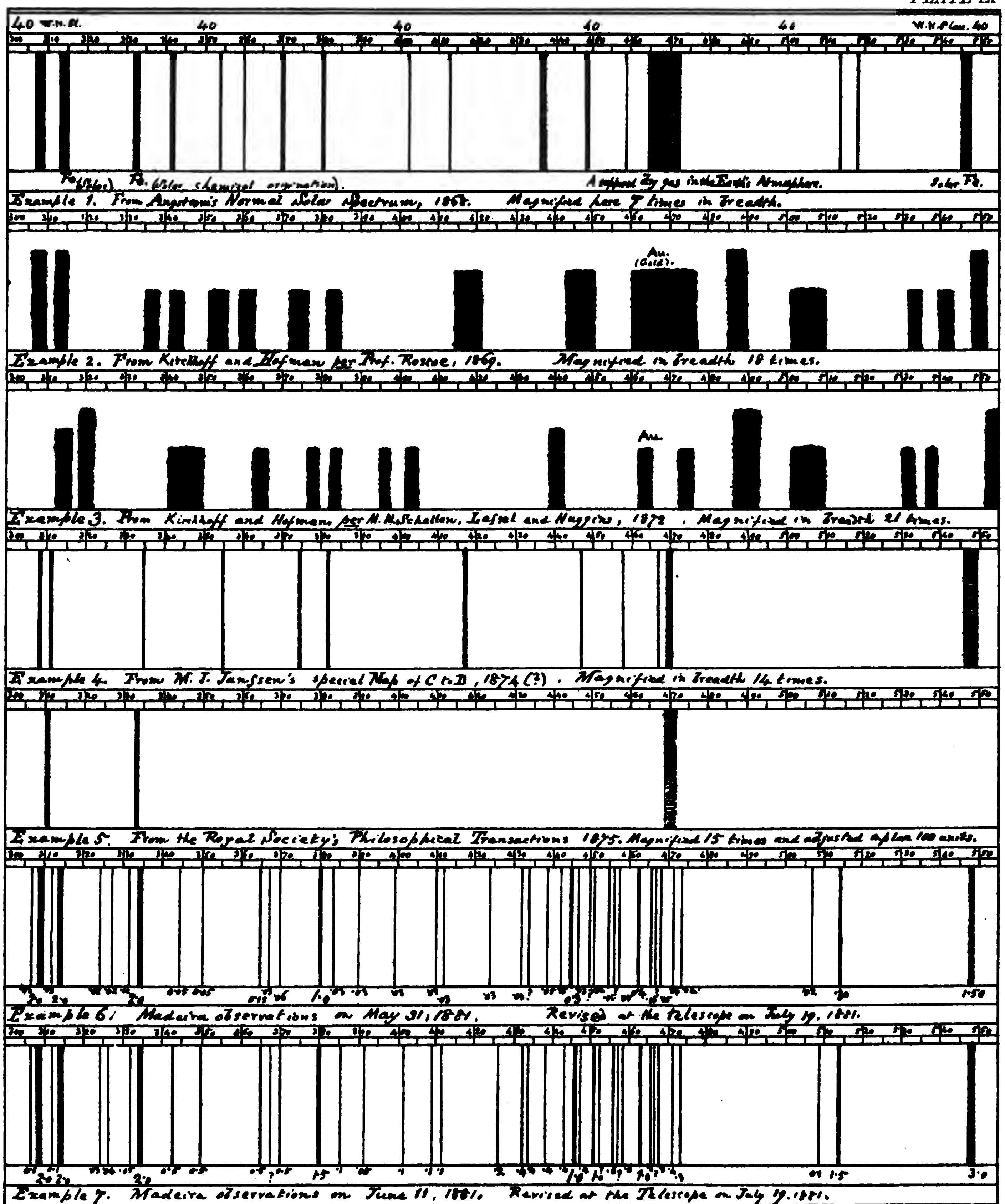


Photo-Lithograph. W. & A. K. Johnston. Edinburgh.

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour · and slanting lines express shading at the place.

Subject 11.—The α (alpha) Band (called also "C[6]," by Sir David Brewster), in a Low Sun.

The spectrum colour of the place, a Full Orange.

PLATE X

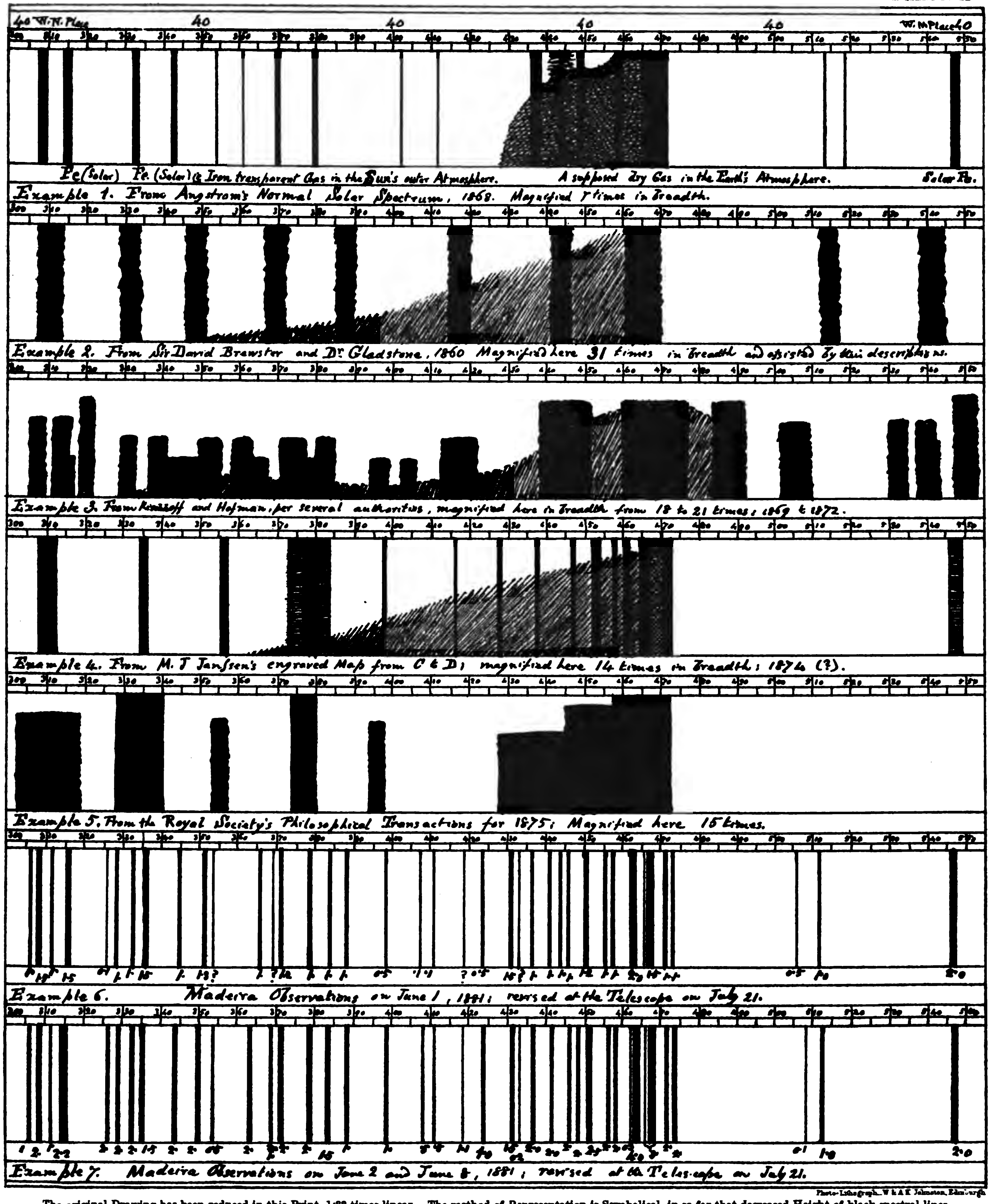


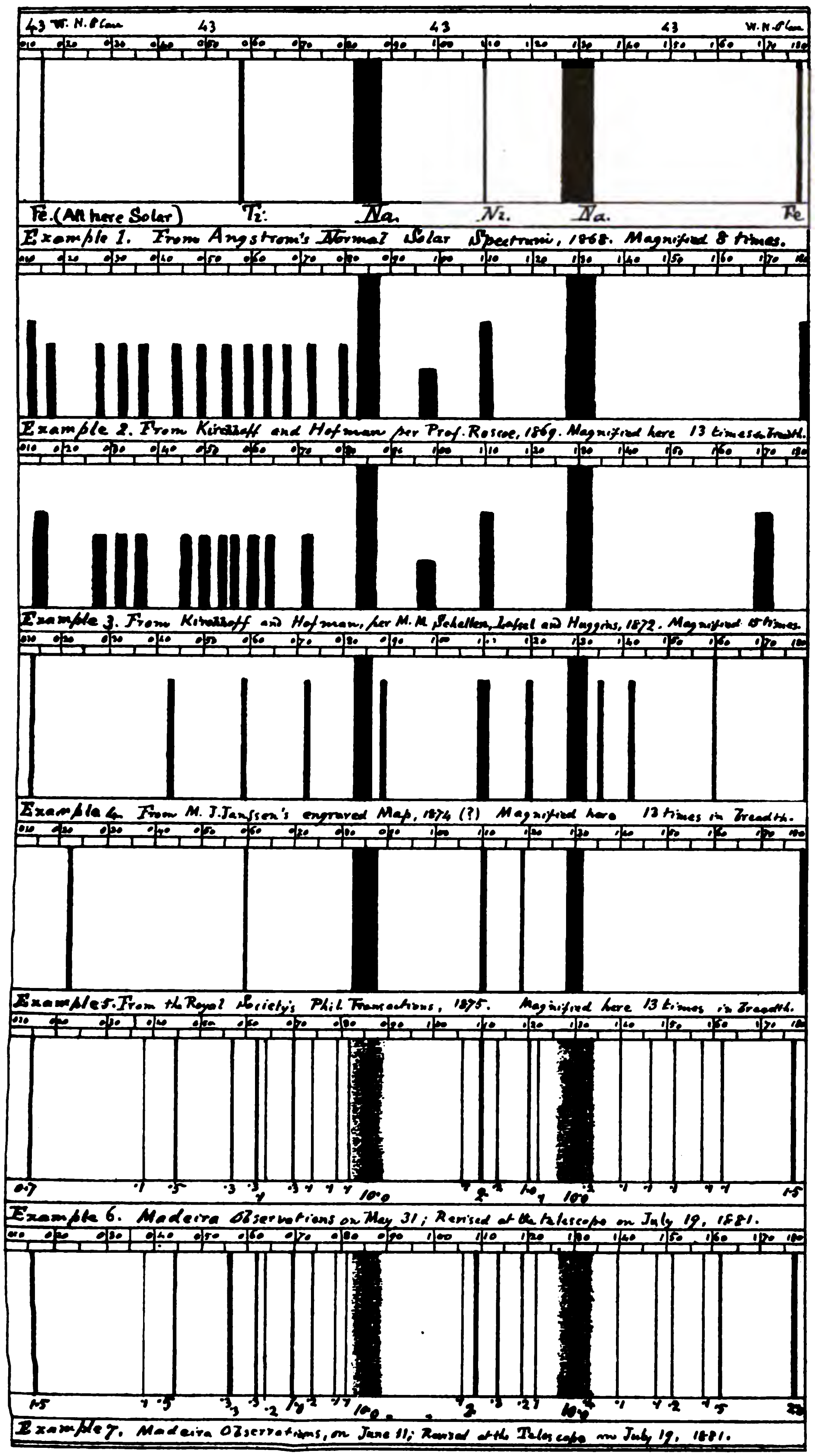
Photo-Lithograph W & A K Johnston, Edinburgh

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

PLATE XI

Subject 12.—The D Lines, in a High Sun.

Spectrum colour of the place, a Full Yellow.



Subject 13.—The D Lines, in a Low Sun.

Spectrum colour of the place, a Full Yellow.

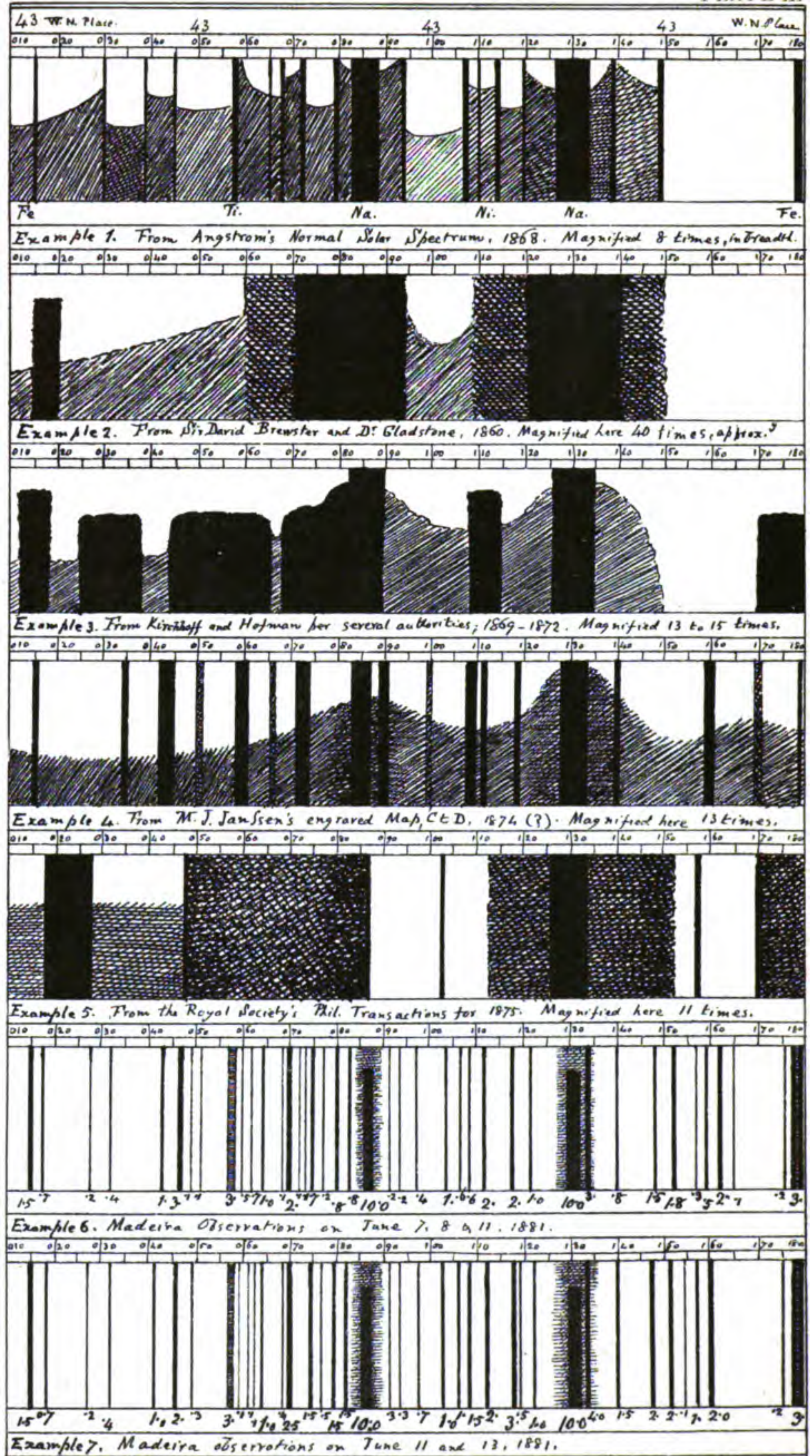


Photo-Lithograph, W & A.K. Johnston, Edinburgh

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

Subject 14.—The Helium Group, under a High Sun,

viz. the Helium and Iron Lines at 47,778 and 47,779 W.N. Pl^s., preliminary to the "Great E" group.

spectrum colour of the region, a light Citron-Green.

PLATE XII

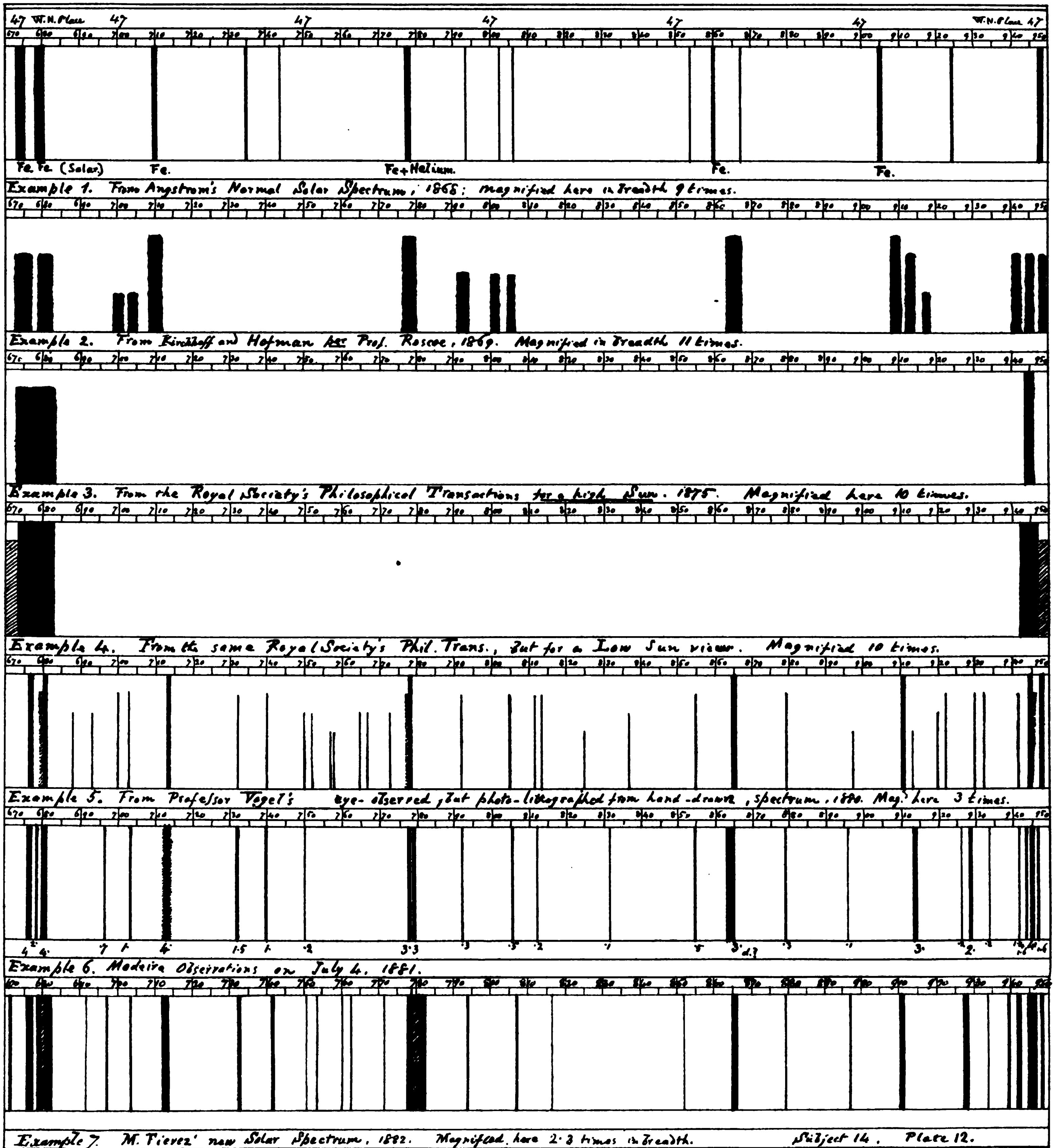


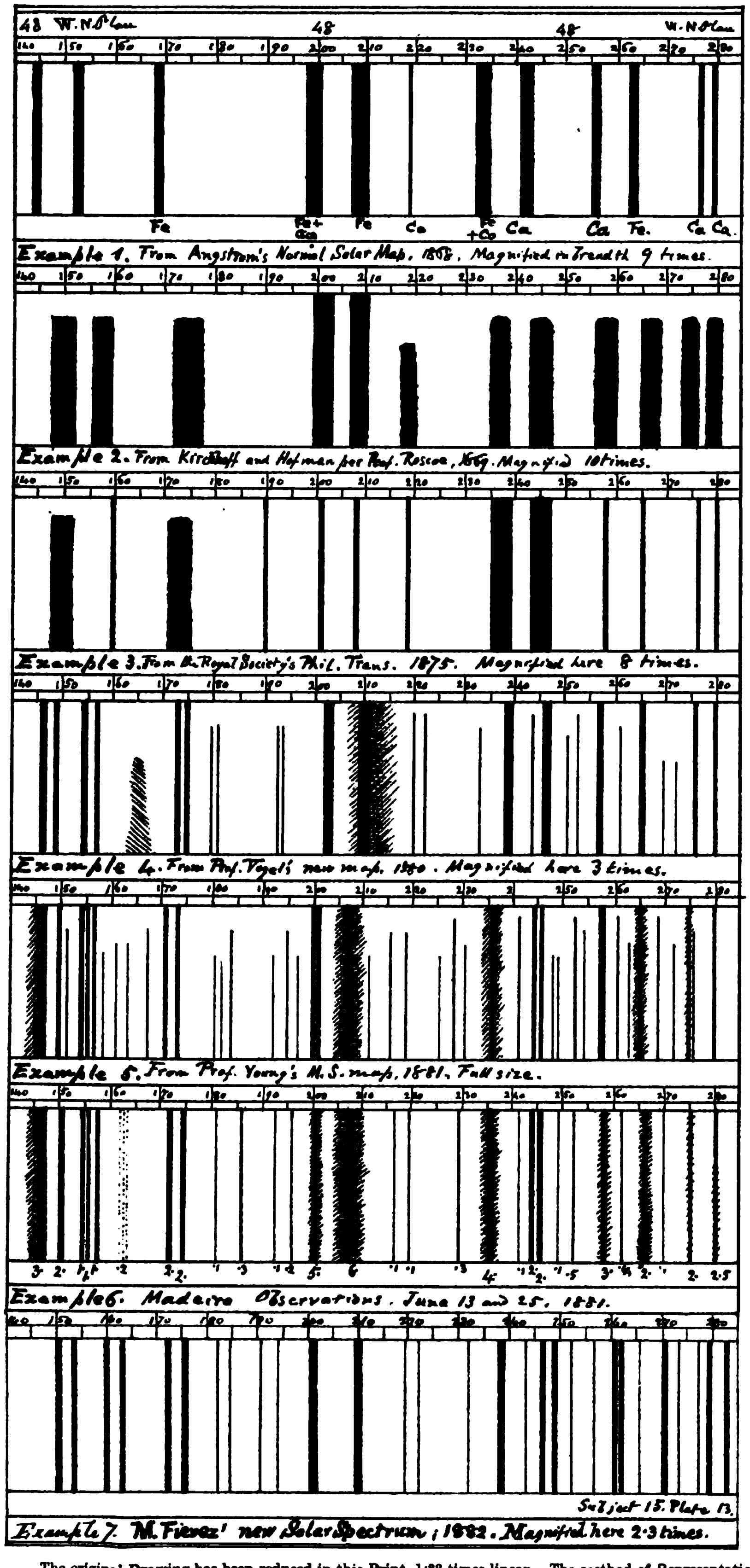
Photo-Lithograph W & A K Johnston Edinburgh

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

PLATE XIII

Subject 15.—The Great E group, in a High Sun.

Spectrum colour, Citron-Green.



Subject 16.—The Bandelet of Lines following E, in a High Sun.

Spectrum colour, Citron-Green.

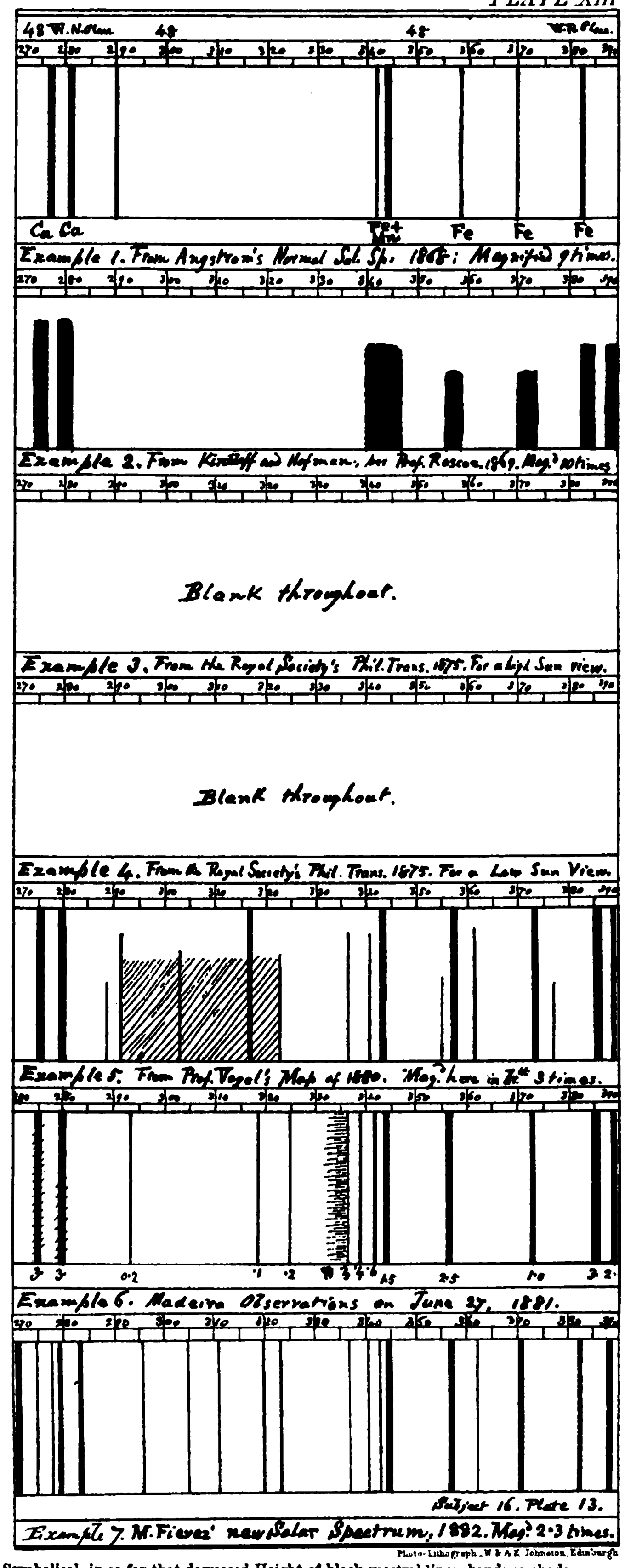


Photo-Lithograph. W. & A.K. Johnston, Edinburgh

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

SUBJECT 17.—A "BASIC" LINE PRECEDING "LITTLE b" IN A HIGH SUN.

SPECTRUM COLOUR OF THE REGION, GREEN.

PLATE XIV

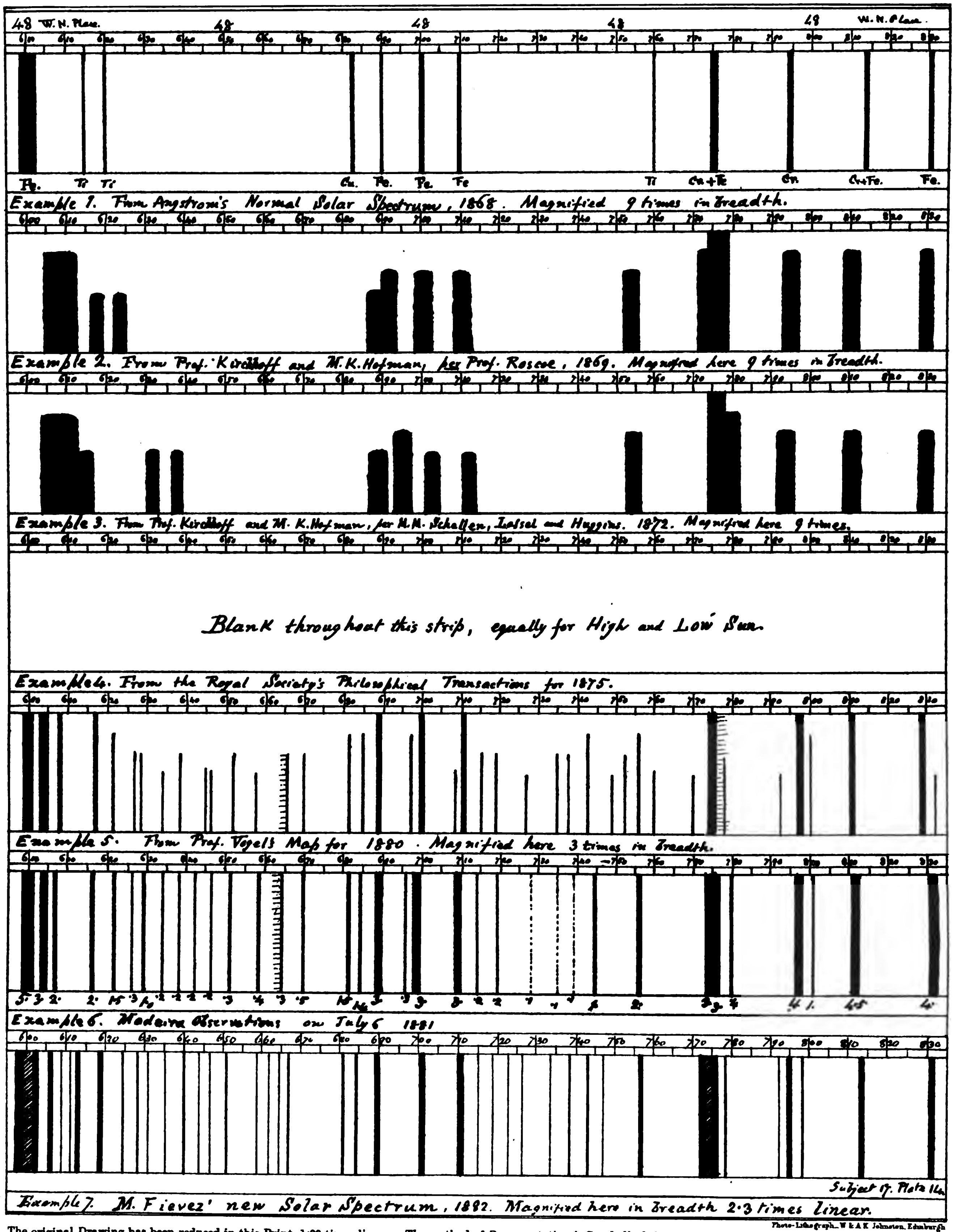


Photo-Lithograph. W. & A. K. Johnston, Edinburgh.

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

SUBJECT 18.—THE "LITTLE b" GROUP, IN A HIGH SUN.

IN THE FULL GREEN COLOUR OF THE SPECTRUM.

PLATE XV

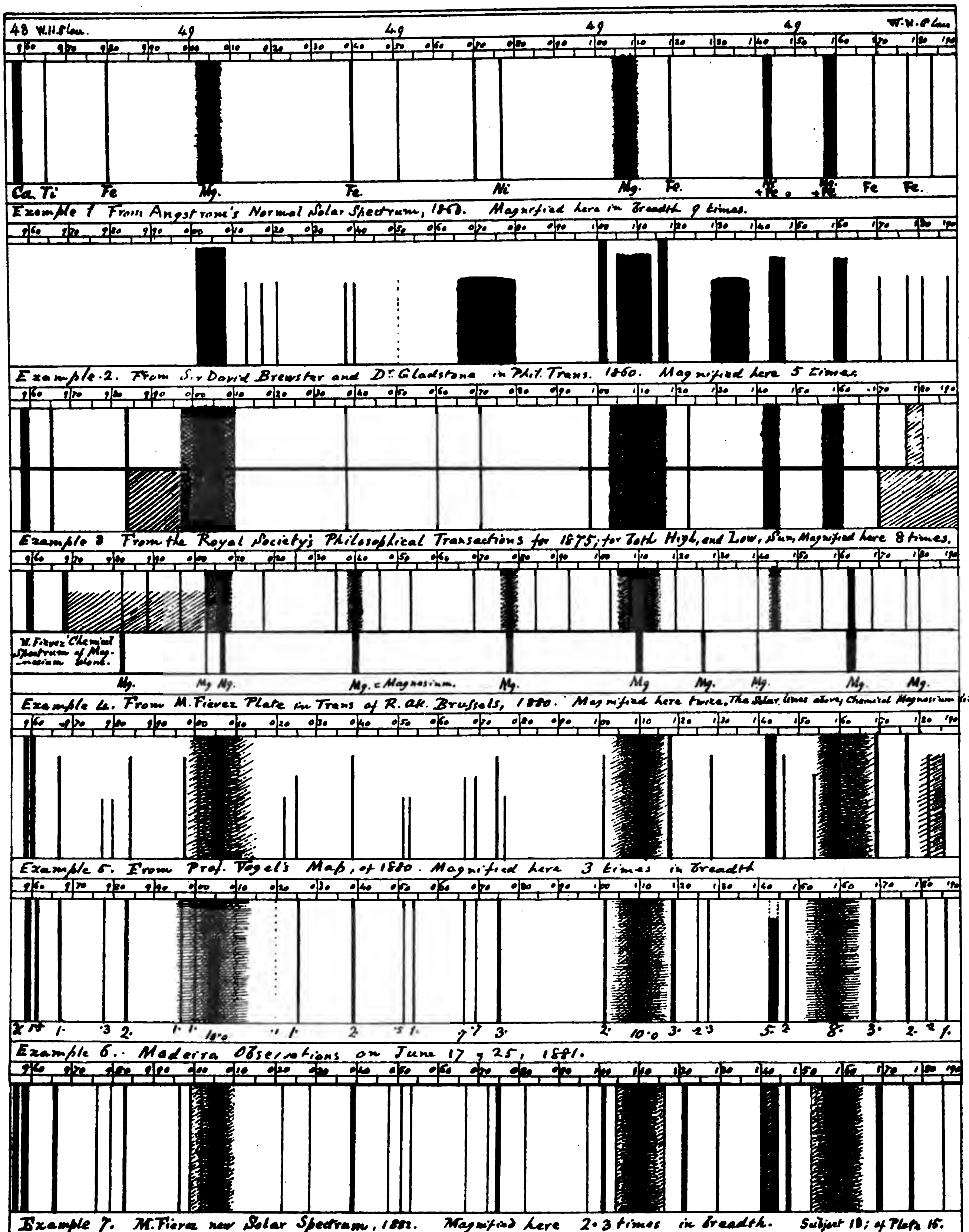
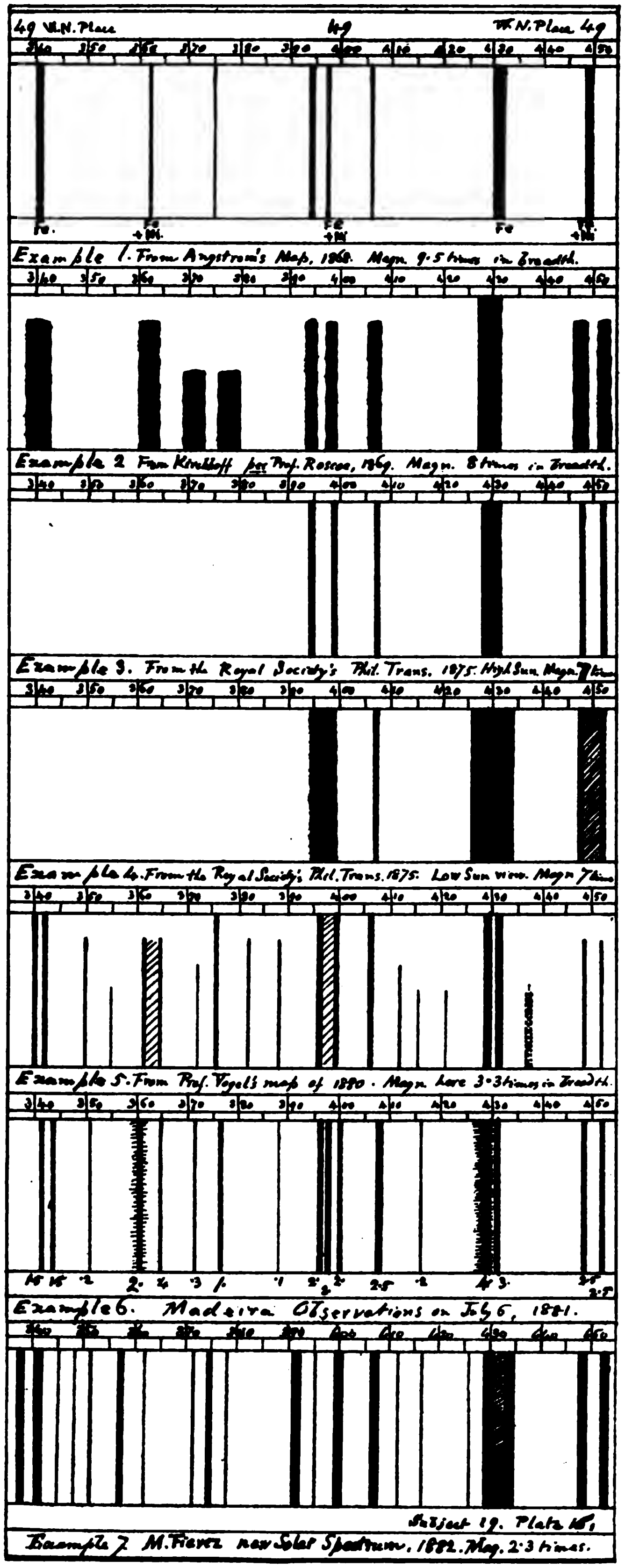


Photo-Lithograph W & A K Johnston Edinburgh

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

Subject 19.—A group following "Little b," with 3 basic lines, in a High Sun. In the Green colour of the spectrum.



Subject 20.—The "Great F" line, in a High Sun. In the Glaucous coloured region of the spectrum.

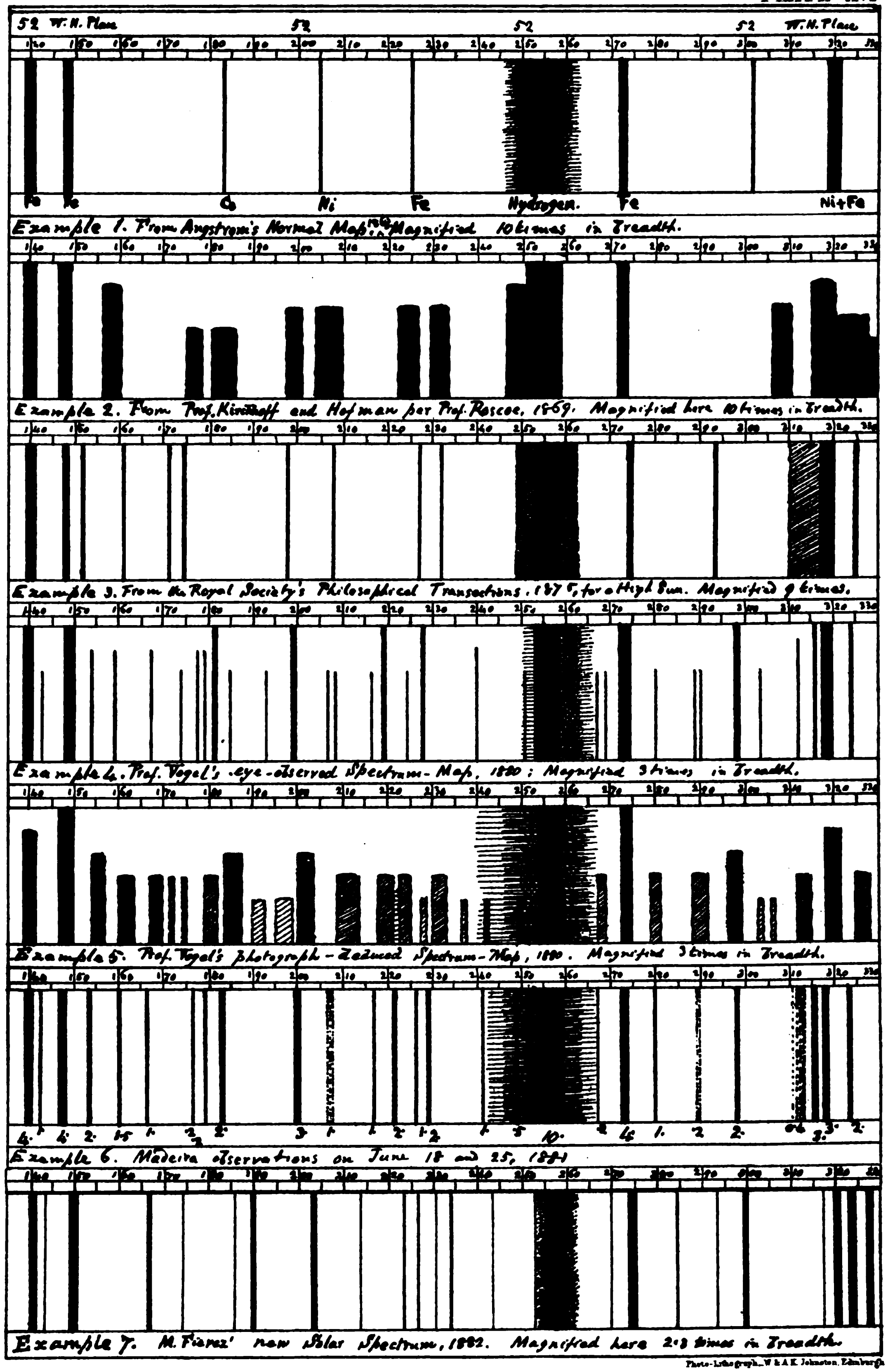


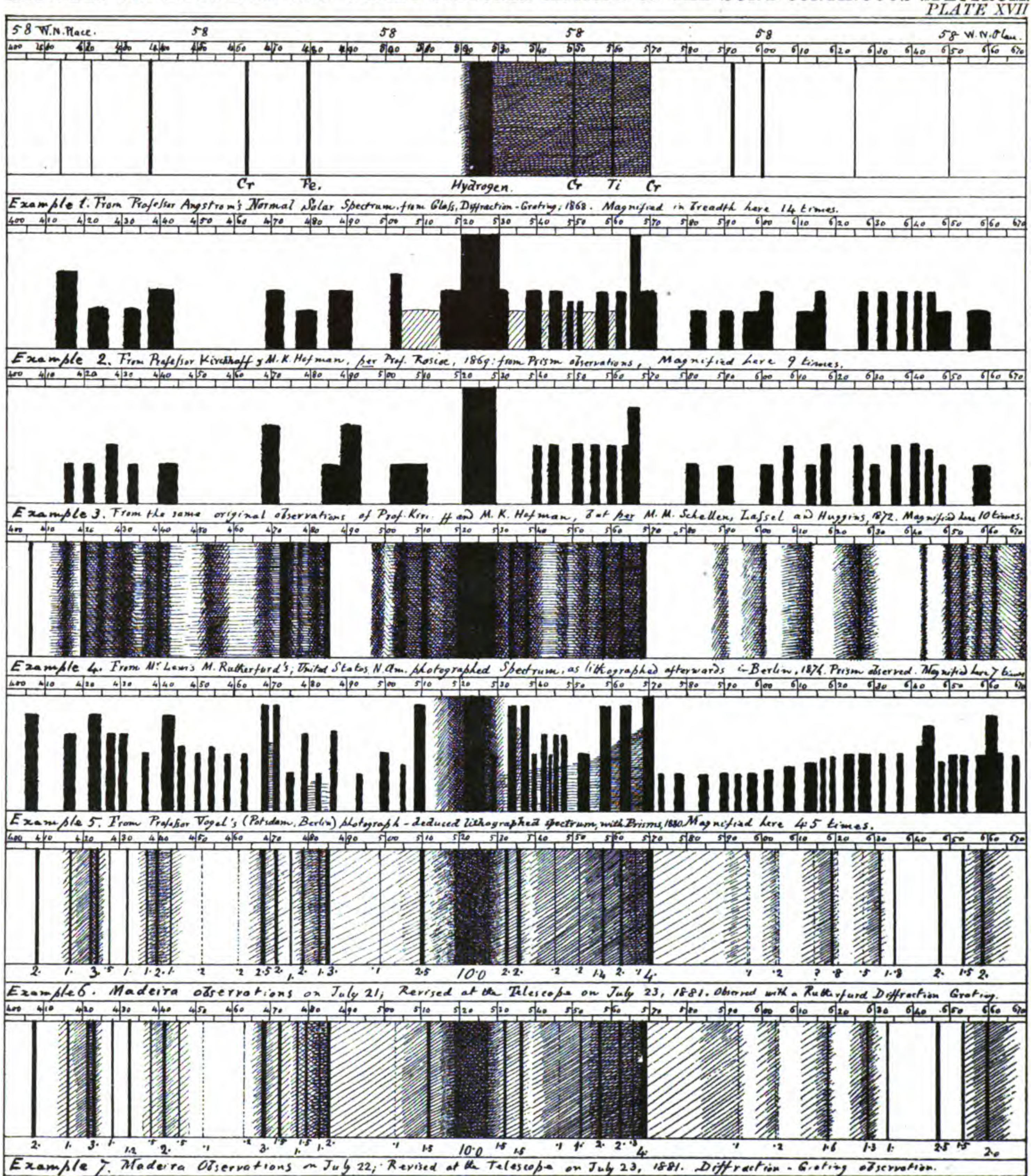
Photo-Lithograph W. & A. K. Johnston, Edinburgh.

The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.

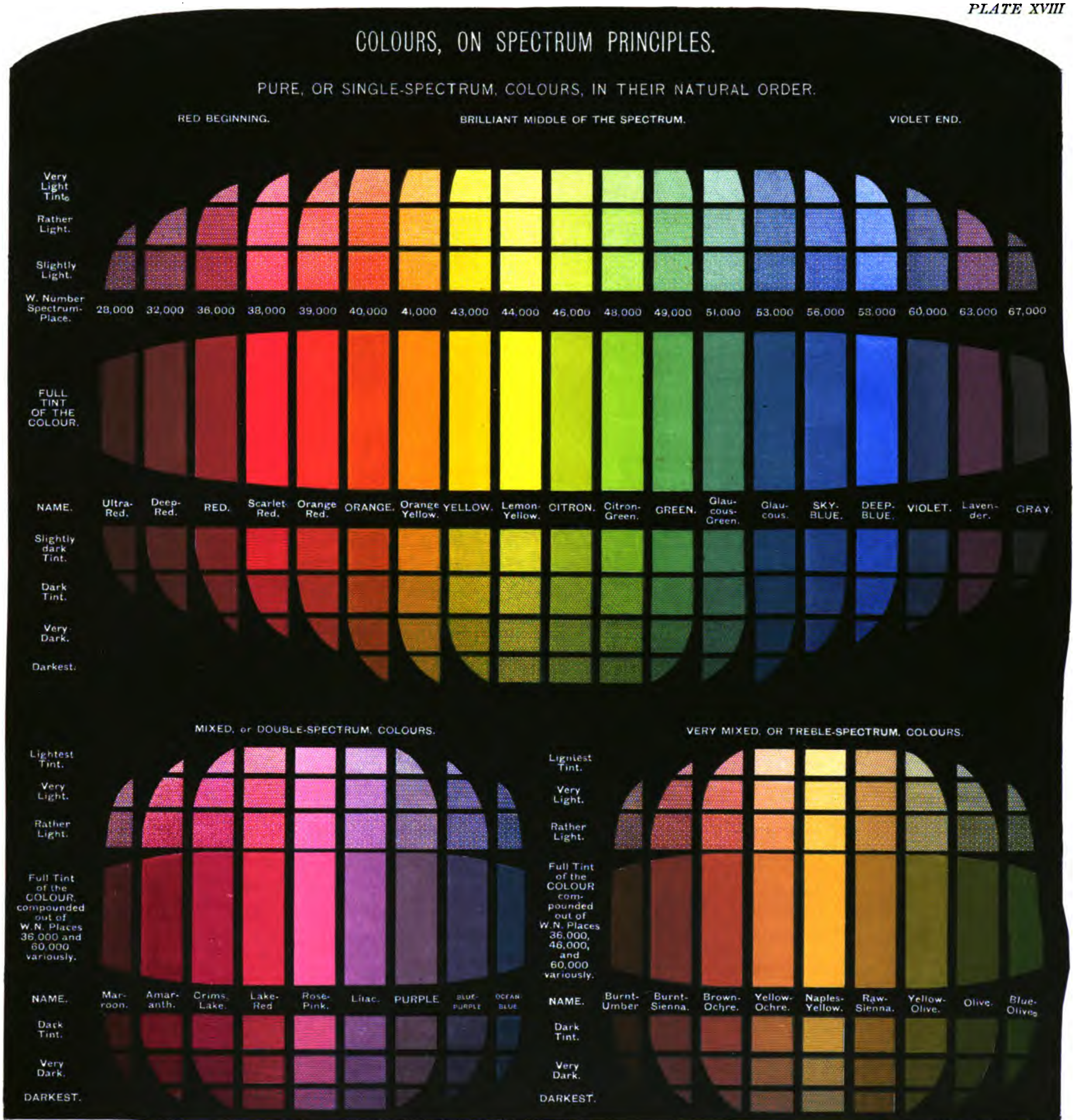
SUBJECT 21.—THE "NEAR G" LINE, OR VIOLET HYDROGEN, IN A HIGH SUN.

BETWEEN THE DEEP-BLUE AND VIOLET COLOURED REGIONS OF THE SUN'S CONTINUOUS SPECTRUM.

PLATE XVII



The original Drawing has been reduced in this Print, 1·33 times linear. The method of Representation is Symbolical, in so far that decreased Height of black spectral lines, bands or shades, stands for paleness of black-colour: and slanting lines express shading at the place.



W & A K Johnston, Edinburgh & London